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Geology and Mineral Resources of Southeastern Franklin County, Pennsylvania

Samuel I. Root

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Geology and Mineral Resources of Southeastern Franklin County, Pennsylvania

by Samuel I. Root
Pennsylvania Geological Survey

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PENNSYLVANIA GEOLOGICAL SURVEY
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HARRISBURG

1968

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PREFACE

This report concerns the origin, history, and possible use of rocks exposed in Franklin County.

Rocks exposed range in age from Precambrian to Ordovician (1100-470 million years ago). They include altered Precambrian volcanics which are the oldest rocks, younger quartzites (a resistant sandstone) of Cambrian age, a thick series of Cambrian and Ordovician limestones and dolomites (calcium and magnesium carbonates), and the youngest rock which is Ordovician shale. The volcanic rocks and quartzites are discussed in general terms, and their character and distribution in the eastern part of the county are noted. The limestones and dolomites of Cambrian-Ordovician age which cover most of the area are discussed in detail. Data concerning the origin of these rocks and their later folding and faulting are presented. Differences in thickness of the various strata and in composition of the rock particles that form these strata are included. Chemical analyses of the carbonates are presented in a number of graphs. Shales of Ordovician age are exposed in the western part of the area. Data concerning their origin and composition are given. This section of the report will be of particular interest to students of geology and natural history.

A considerable portion of the report is concerned with economic uses of the rocks and minerals in the area. This will be of particular interest to mineral industries, professional geologists, urban and rural planners, construction engineers, and conservationists. The mineral history of the area is reviewed and current activities are noted. Specifications for magnesium compounds, chemical grade limestones, coarse aggregate, fine aggregate, dimension stone, and lightweight aggregate and brick are listed. Those rock strata which meet these specifications are discussed. In addition the ground-water yield of the various rock strata are analyzed; also what geologic conditions control locations that should be most productive.

A detailed geologic map shows the distribution of various rock strata and where they are folded and faulted. This map is important for purposes of mineral extraction, for various types of construction, and for location of water wells.

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GEOLOGY AND MINERAL RESOURCES OF SOUTHEASTERN FRANKLIN COUNTY, PENNSYLVANIA

By

SAMUEL I. ROOT

ABSTRACT

This report concerns the geology of about 170 square miles in southeastern Franklin County. The easternmost portion of the mapped area includes South Mountain which is part of the Blue Ridge physiographic province but most of the area includes lowlands of the Great Valley.

Rocks underlying South Mountain consist of Precambrian Catoctin greenstones overlain by about 4,000 to 5,000 feet of resistant quartzites of the Lower Cambrian (?) Weverton and Harpers Formations and Lower Cambrian Antietam Formation.

In the Great Valley, marine carbonate rocks of Lower Cambrian to Middle Ordovician age compose most of the terrain. From earliest to latest these are the Tomstown Formation, Waynesboro Formation, Elbrook Formation, Conococheague Group, Beekmantown Group, St. Paul Group, and Chambersburg Formation. These units probably aggregate about 14,000 feet, predominantly limestone, with minor amounts of dolomite, some shaly limestone, and two thin sandstone horizons.

The Martinsburg Formation, a flysch sequence of Middle and Upper Ordovician age shales and graywacke, overlies the carbonates on the west side of the mapped area. Structural complications in this unit do not permit establishment of an internal stratigraphy or thickness.

With the exception of the western Martinsburg belt all rocks are structurally part of the South Mountain anticlinorium. Rocks from the Catoctin greenstones to Middle Ordovician carbonates are involved in related folding and faulting. The regional flow cleavage (S_1) and fold pattern geometry are reflected through the entire sequence of rocks indicating that they were deformed as a single unit. All major faults are rectilinear high angle reverse faults. The area is dominated by many parallel asymmetric to overturned folds and parallel faults which can be traced more than 30 miles to the Potomac River, where further extension is limited only by the lack of detailed mapping. In the extreme eastern part of the area deformation was of the passive flow type, but over most of the area deformation was of the flexural slip type.

The Martinsburg beds are structurally part of the Massanutten synclinorium. There are insufficient outcrops and marker beds to decipher the structure, but in several large outcrops type and amount of deformation observed differs somewhat from that of the older carbonates.

Several homoaxial stages are recognized in deformation of the area. These include folding and later faulting and block translation. These may be secular rather than continuous events in view of the tectonic history of the region which involves multiple deformations.

Economic resources include chemical and metallurgical grade limestones that may be exploited locally. Much of the limestone in the area is suitable for class A coarse aggregate. The Antietam Formation yields class A fine aggregate. Shales of the Martinsburg have potential use as lightweight aggregate as well as building brick, face brick, and floor tile. Ground-water resources are discussed in terms of potential yield.

INTRODUCTION

This report covers the geology of the southeastern portions of Franklin County. The area concerned in this report includes the Greencastle and Waynesboro 7½-minute quadrangles as well as portions of the adjoining Williamson, Mason-Dixon, Hagerstown, and Smithsburg 7½-minute quadrangles. Emphasis is placed on the Cambro-Ordovician limestones because of their possible economic utility. The older rocks of the Antietam Formation form the eastern boundary of the geologic mapping. The younger shales of the Martinsburg Formation, although only partially mapped, form the western limit of detailed mapping.

PHYSIOGRAPHY

Southeastern Franklin County lies principally in the Great Valley section of the Valley and Ridge province and is locally referred to as the Cumberland Valley. The eastern part of the mapped area lies on the South Mountain extension of the Blue Ridge province (Figure 1).

The Great Valley section near Waynesboro and Mont Alto on the east, has elevations of almost 800 feet but the surface slopes to the west with elevations at Greencastle and Marion of about 550 feet. Northeast-southwest trending limestone ridges impart a gently rolling aspect to the terrain. Streams are small, usually impermanent, flowing in broad

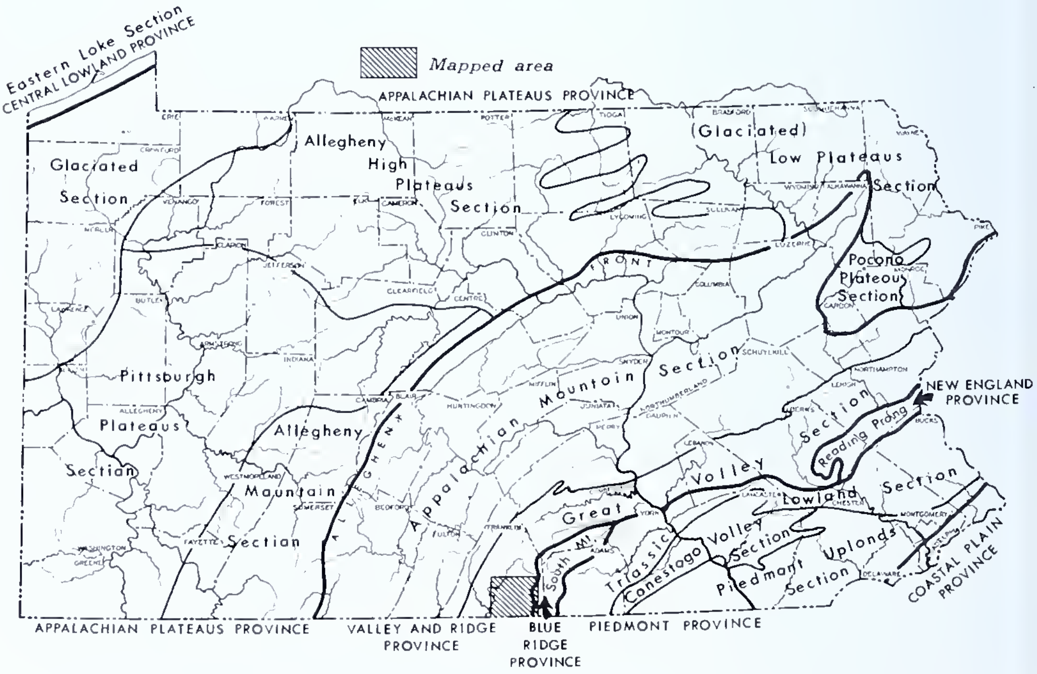

Figure 1. Location of mapped area and physiographic provinces of Pennsylvania.

valleys. West of Greencastle and Marion, shale of the Martinsburg Formation floors the valley. This shale area is 100 to 150 feet higher than the adjacent limestones, and is complexly dissected by streams with steep valley walls. The large permanent streams of the Cumberland Valley are restricted to the shale area, generally meandering in small, steep-walled valleys. Conococheague Creek flows close to the limestone-shale contact for a considerable portion of its length.

The South Mountain extension of the Blue Ridge province rises steeply from the limestone valley floor which borders it on the west. The first narrow ridge, which is composed of Antietam quartzite, attains elevations of 1,600 to 1,700 feet. Inner ridges of the Mont Alto Quartzite Member of the Harper Formation attain elevations of more than 1,800 feet. Immediate local relief is 800 feet and maximum relief is 1,000 feet. The topography is rugged on South Mountain and streams flow in narrow steep-walled valleys controlled by structure.

PREVIOUS WORK

The geology of Franklin County was first investigated in the early 1800's by members of the First Pennsylvania Geologic Survey. A small scale map showing the distribution of the limestone and shale under the name of Auroral limestone and Matinal slate was published by H. D. Rogers in 1858. The Second Pennsylvania Geologic Survey studied the area in some greater detail and a map was published at the scale of 2 miles to 1 inch by R. H. Sanders in 1881 and again by J. P. Lesley in 1885. At the turn of this century the area was mapped by Stose (1909) who subdivided the limestone into many units still in use and recognized the structural complexity; indeed this excellent reconnaissance work is the foundation of all later geologic work in the Cumberland Valley.

Subsequent work in this area has mainly been regional stratigraphic, structural or local economic studies. The most significant work in recent years has been that of Sando (1957, 1958) who subdivided the Beekmantown Group in Maryland into several mappable units. He extended his mapping from Maryland about 1 mile into southernmost Franklin County. Other workers in recent years who have contributed to an understanding of the carbonate stratigraphy are Craig (1949), Wilson (1952), Neuman (1951), and Root (1964). The most noteworthy study of structural geology in the Cumberland Valley is that of Cloos (1947, 1951). Cloos' 1951 study also includes some stratigraphic information. A student of Cloos (Fellows, 1943) briefly examined some areas in Franklin County pursuant to a regional structural study of tectonites. The general structure has also been described by Sando (1957), Root (1965), and MacLachlan and Root (1966).

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Stimulating and fruitful discussions and field trips were made with W. J. Sando, V. E. Gwinn, D. U. Wise, and R. Scholten. The preparation of the report was facilitated by many members of the Pennsylvania Geological Survey and Dr. R. B. Newman of the U. S. Geological Survey.

STRATIGRAPHY

Bedrock exposed in southeastern Franklin County ranges in age from Precambrian to Upper Ordovician (Figure 2). Except for a small area of volcanics in the northeast corner of this area, the bedrock is sedimentary. Some surficial deposits occur as alluvium in stream valleys and as colluvium at the base of South Mountain.

Information concerning the Catoctin greenstones and arenaceous sediments of the Weverton, Harper, and Antietam Formations is almost entirely derived from the work of Stose (1909) and is only included in this report for the purpose of completeness. These sediments aggregate about 4500 feet in thickness.

The seven mapped Cambro-Ordovician limestone units, about which this report is principally concerned, aggregate to about 13,500 feet in thickness. The thickness of the Martinsburg shale has not yet been determined satisfactorily.

The general disposition of the rocks is simple. The arenaceous sediments rim a central core of volcanics in the eastern part of the area. The Cambro-Ordovician limestones rim the arenaceous sediments. To the west the limestones are faulted against the shales of the Martinsburg Formation. Thus there is a progression of successively younger rocks from east to west; from the Blue Ridge anticlinorium to the Massanutten synclinorium.

Outcrop in the area of South Mountain is very poor. Limestones are fairly well exposed in the Great Valley except where colluvium and alluvium at the base of South Mountain cover most of the bedrock. The Martinsburg Formation decomposes readily to soil and is poorly exposed except in a few recent road cuts.

PRECAMBRIAN SYSTEM

Catoctin Formation

In the area of Rocky Mountain Creek near Mont Alto Sanatorium is a small area, mapped by Stose (1909), that contains both metarhyolite and metabasalt included as the Catoctin Formation. The metarhyolite is an altered rhyolite lava, finely laminated by flow structure, and in

System	Series	Group	FORMATION	DESCRIPTION	THICKNESS (in feet)
ORDOVICIAN	Middle Ordovician		Martinsburg Formation	Black, carbonaceous and fissile shale, weathers buff, with yellow-green to dark-gray fine-grained graywacke beds.	>1,000
			Chambersburg Formation	Dark-gray, cobbly limestone, argillaceous, with abundant irregular shaly partings Some metabentonite beds present.	750
		St. Paul	New Market Row Park	Vaughanitic limestone at top. Granular fossiliferous limestone, black chert, and sparse dolomite in middle. Vaughanitic limestone at base.	1,000
		Beekmantown	Pinesburg Station Dolomite	Light-colored, thick bedded, finely-laminated dolomite.	450
	? Lower Ordovician		Rockdale Run Formation	Mostly mechanical and stromatolitic limestone. Laminated light gray or buff dolomite interbeds in upper half. Some chert in middle and at top. At base ±500 feet of pure marbleoid limestone, locally with abundant chert and pink stromatolitic limestone.	+2,500
			Stonehenge Formation	Stromatolitic and fine-grained mechanical limestones that become predominantly mechanical toward the north.	775
			Stoufferstown Formation	Coarse-grained mechanical limestone with dark-gray siliceous seams, prominent ridge former.	260
CAMBRIAN	Upper Cambrian	Conococheague	Shadygrove Formation	Pure light-colored limestones, stromatolitic in part. Abundant pinkish limestones and cream colored cherts.	650
			Zullinger Formation	Cyclically-bedded stromatolitic-mechanical limestone, interbanded limestone and dolomite, interlaminated limestone and dolomite, thin dolomite. Several thin local quartz sand beds.	2,500
	Middle Cambrian		Elbrook Formation	Light-colored, calcareous shale and argillaceous limestone, blue limestone and dolomite in middle ridge former. Pure dark limestone at base.	estimated ±3,000
	Lower Cambrian		Waynesboro Formation	Thin buff basal and upper red ridge-ofrming sandy units. Middle portion is blue limestone.	±1,000
			Tomstown Formation	Dolomitic limestone to limestone in upper part. Mottled silty dolomite in middle part. No exposures at base.	estimated 1,000 —
		Chilhowee	Antietam Formation	White quartzite with bluish-cast in places, coarse grained, pure, with many skolithos tubes.	500-800
CAMBRIAN ?	Lower Cambrain ?		Harpers Formation	Dark-banded, hackly schist to slate with prominent middle member of massive hard, white quartzite that thickens to the north.	2,750
			Weverton Formation	Gray fel spathic sandstone, coarse grained. Some white quartzites. Conglomerate at base.	1,250
PRECAMBRIAN			Catoctin Formation	Altered rhyolitic flows, finely-laminated, red to purple color. Altered basalt with chlorite and epidote.	

Figure 2. The stratigraphic column in southeastern Franklin County.

places spherulitic and porphyritic; usually red to purple in color. The metabasalts are altered basalt flows containing amygdules filled with chlorite, epidote, and quartz and veined by epidote and asbestos. Usually they are altered to greenstone and chlorite schist. Both volcanics form rolling intermontane valleys, are densely forested, and have thin soil.

CAMBRIAN? SYSTEM

The Weverton and Harpers Formations are included in the Cambrian system although their age is in doubt and they could be Precambrian. No diagnostic fossils have been found in these units and they are stratigraphically below the Lower Cambrian *Olenellus*-bearing Antietam Formation.

Weverton Formation

According to Stose (1909) the Weverton, which is 1,250 feet thick, is composed of coarse, gray feldspathic sandstone and white quartzose sandstone with purplish arkose and hard purple quartz conglomerate at the base. It forms high wooded ridges and rocky ledges with meager soil.

Harpers Formation

Overlying the Weverton with apparent conformity is the Harpers Formation. According to Stose (1909) this formation, which is approximately 2,700 feet thick, is composed of dark-banded, tough hackly schist or slate and thin flaggy sandstones. A middle unit, the Mont Alto Member is composed of massive hard white *Skolithos*-bearing quartzite several hundred feet thick. It forms smooth topped, high wooded ridges and densely forested intermontane valleys, with a soil that is clayey and sandy.

CAMBRIAN SYSTEM

Antietam Formation

Conformably overlying the Harpers Formation is the Antietam Formation. It is composed, according to Stose (1909), of 500 to 800 feet of coarse-grained white and bluish gray quartzite and sandstone containing numerous long *Skolithos* tubes. It weathers readily to sand and forms rocky wooded ridges and slopes with a sandy rocky soil. Various early Cambrian fossils including: *Obolella minor, Hyolithes communis,* and fragments of *Olenellus* have been collected from the Antietam in the Cumberland Valley (Amsden, in Cloos 1951, p. 102).

The distribution of the volcanics and Weverton, Harpers, and Antietam Formations is shown in general terms on the accompanying geologic map (Plate 1). For details concerning the distribution of these units in Franklin County the reader is again referred to Stose (1909). In adjacent areas Cloos (1951) furnishes information in Maryland; Fauth

(1968) and Freedman (1967) have mapped the areas of South Mountain near Chambersburg and Mt. Holly Springs respectively.

Tomstown Formation

The Tomstown Formation was named by Stose (1906, p. 208) from exposures near the town of Tomstown in southeastern Franklin County. The Tomstown Formation was originally called the Tomstown Limestone. The stratigraphic policy of the Pennsylvania Survey is to call mapped rock units by the formal terms Group, Formation or Member rather than by lithologic terms, thus previously named map units have been modified accordingly. According to Stose (1909, p. 5) "it is composed largely of dolomite and limestone, massive and thin-bedded, and in part cherty, with considerable shale interbedded near the base."

The Tomstown Formation is restricted to a narrow zone paralleling South Mountain. The unit everywhere forms a rolling lowland bounded on the east by the rugged ridges of the Antietam quartzites and on the west by the low ridges and knobs of the basal Waynesboro Formation. It is the most poorly exposed unit in the area. Colluvial material moving down the high Antietam ridges covers all of the Tomstown at the base of the mountain. Alluvial deposits of the West Branch of Antietam Creek east and north of the town of Tomstown and Red Run Creek south of Rouzerville cover most of the Tomstown in the valleys. There are less than a dozen isolated outcrops of the Tomstown Formation in the mapped area.

Because of the paucity of outcrop it is impossible to construct a lithostratigraphic column of the Tomstown. One can only obtain a general idea of the lithology based on scattered outcrops. The best outcrop of this unit is at Blue Rock School about 1 mile southeast of Tomstown. Here about 15 feet of gently dipping dolomite is exposed. The thin- to medium-bedded dolomite is light gray, finely crystalline, irregularly mottled with small patches and partings of brick red to yellow argillaceous dolomite. The amount of acid insoluble constituents (silt-size quartz grains and clay) vary as indicated by three dolomite samples which contained 0.8, 4.1, and 11.8 percent insolubles. From structural consideration it appears that this lithology is in the middle of the formation.

Another nearby outcrop of Tomstown (.65 miles S40°E of the road intersection at the town of Tomstown) is also composed of dolomite. It is almost white in color on the fresh surface, very thick bedded and has variable amounts of well-rounded floating coarse quartz grains and creamy dolomite pellets. This rock is quite porous but has little permeability. Pores are up to 2 mm across and appear to be leached carbonate rhombs. No more than 5 feet of this lithology is exposed, and stratigraphically it appears to be slightly higher in the section than the dolomite at Blue Rock School.

About 2,000 feet due west of Midvale, in extreme southeastern Franklin County are several exposures that are stratigraphically probably in the upper third of the unit. The lithology here is bluish-gray, finely crystalline, mottled to banded limestone. Some beds of pure, light colored marbleoid limestones also occur. Some dolomite bands and thin beds are dispersed throughout the limestones. Structural complexities make it difficult to ascertain thickness of the exposed beds but they represent about 50 to 100 feet of section.

The uppermost beds of the Tomstown are also composed of limestone. This is well shown 0.8 mile southwest of Blue Rock School where ledges of blue, silty dolomitic limestone occur below the siltstone and sandy dolomite float of the basal Waynesboro Formation. West of Roadside, at the dam site of Waynesboro Country Club, are beds of blue limestone interbanded with minor amounts of gray dolomite. Some small nodules of black chert occur in the limestone. Across the road from the dam site the Tomstown-Waynesboro contact is well exposed at the base of a prominent Waynesboro ridge, and the very uppermost Tomstown is blue limestone.

Exposures of the lower part of the Tomstown Formation were not observed because this interval is obscured by a thick colluvial cover derived from the ridges of South Mountain. Stose (1909, p. 5) observed the basal Tomstown in iron-ore pits and concluded that shales interbedded with dolomite compose the base of the formation.

The base of the Tomstown is picked below the abrupt change from the sharp ridges of the Antietam Formation to the rolling colluvium covered hill slope. As there is no outcrop the selection of the contact on the colluvial slope is good where beds are subvertical but only fair where beds are gently dipping. The top of the Tomstown is picked at the base of the prominent lower ridge-forming unit of the Waynesboro Formation. North of Quincy this topographic break between the two formations is not prominent and the contact is somewhat questionable.

There is considerable question about the thickness of the Tomstown Formation. A thickness of 1,000 feet was computed by Stose (1909, p. 8). The writer has computed thicknesses of 1,350 feet and 2,100 feet in structure sections based on outcrop width and general dip across the area of Blue Rock School and Fairview respectively. There are no complete sections in Franklin County or across the state line in Maryland, but Cloos (1951, p. 49) points out that variability of thickness in this unit may well be deformational and related to its position in the crest of the South Mountain fold.

Lower Cambrian fossils such as *Salterella, Kutorgina,* and *Olenellus* were reported from this formation in Franklin County (Stose, 1909, p. 5).

Waynesboro Formation

The Waynesboro Formation was named by Stose (1906, p. 209) for exposures near the town of Waynesboro in southern Franklin County. According to Stose (1909, p. 5) and Bassler (1919, p. 66) there is a three-part division of the Waynesboro with lower and upper ridge-forming sandy units and a middle valley-forming limestone unit.

The Waynesboro Formation occurs in a narrow belt, about 2,000 feet wide, from Pond Bank almost to Waynesboro. At Waynesboro, where it is best exposed, it widens to nearly a mile in width as it passes onto one of the axes of the South Mountain anticlinorium. East of Waynesboro the formation occurs in two narrow belts that merge toward the northeast. A double ridge, that corresponds to the upper and lower sandy units, characterizes the Waynesboro. The middle limestone portion underlies a valley. From Waynesboro south the terrain is composed of rolling ridges but to the north the terrain is more broken and hilly.

Although the Waynesboro Formation has better outcrops than the Tomstown Formation, there was no place where there was sufficient outcrop to measure a section. The base of the Waynesboro is well exposed 1,000 feet west of Roadside, opposite the dam of the Waynesboro Country Club, where it forms a prominent ridge. The base, which is gradational into the Tomstown, is placed at a 20-foot thick zone composed of buff dolomite and sandy dolomite. The sandy dolomite contains as much as a 30 percent acid insoluble material—mostly very fine-grained to silt-size quartz, some illitic mica, and traces of albite. Above this is an interval of 150 feet in which a few beds of dolomite and interbanded limestone and dolomite occur. This in turn is succeeded by another 150-foot interval, which may be part of the middle unit, with scattered outcroppings of limestone ledges, the uppermost of which are complexly folded. The thin sandy dolomite unit forms the lower ridge of the Waynesboro. Blocks of residual sandstone, chert, and white vein quartz derived from this unit often litter the slopes of the lower ridge former.

The middle and thickest part of the Waynesboro is composed of limestone which because of its relatively soluble nature is poorly exposed and underlies a valley. The limestone ranges from dark blue and massive to a fine-grained white marble. Several dolomite beds are present. In limited outcrop it is difficult to distinguish between these limestones and those of the upper part of the Tomstown. Towards the top, the limestone becomes siliceous and grades into the uppermost division.

The upper ridge-forming unit is composed of flaggy, dark-red to purple sandy shale and siltstone. Some thin-bedded, ripple-marked, fine-grained sandstone beds are also present. Rocks of this part of the Waynesboro Formation are best exposed at the town of Waynesboro, especially at the cemetery on State Highway 16. It is estimated that the thickness of this unit is less than 100 feet.

As mentioned previously, the base of the Waynesboro Formation is picked at the base of the ridge-forming lower unit. As this is mainly a limestone-against-limestone contact, there is some doubt as to the contact where there is no prominent topographic break. The top of the Waynesboro is more apparent. The upper ridge which is more prominent than the basal ridge and the unique red and purple shales and siltstones set it off from the nonresistant gray-green shales and limestones at the base of the overlying Elbrook Formation.

Insufficient outcrop to determine structure or stratigraphic section made calculation of thickness difficult. Stose (1909, p. 5) calculated an approximate thickness of 1,000 feet of Waynesboro Formation. Farther south, in Maryland, Cloos (1951, p. 43) measured 600 feet of Waynesboro Formation. Near Waynesboro, two sections, based on width of outcrop and dip, vary from 1,200 to 1,400 feet in thickness, but allowing for structural thickening the approximate thickness of 1,000 feet that Stose calculated appears reasonable.

Along Red Run Creek, 4,500 feet north of the state line, a thickness of 1,600 feet was calculated. However, as the beds are subvertical and on the limb of a fold in an area of intense thickening, as shown by oolite deformation (Cloos, 1947, pl. 9) the thickness should be considerably reduced. A thickness of about 1,000 feet is probably of the correct magnitude.

A Middle Cambrian age, based on a meager fauna, has been assigned to the Waynesboro Formation by Stose (1909, p. 5) and Bassler (1919, p. 74).

Elbrook Formation

The Elbrook Formation was named by Stose (1906, p. 209) for a thick series of shaly limestones and calcareous shales. There is a threefold division within the formation but general lack of outcrop is an impediment to the understanding of this formation.

The distribution of the Elbrook is complex as it occurs in the core of several large anticlines. From Quincy west it forms a belt 3 miles wide where three anticlines all expose Elbrook in the core. The belt diminishes in width as it swings crescentically about the town of Waynesboro and it is only 1 mile wide along the Pennsylvania-Maryland State Line. The upper and lower portions of the Elbrook form rolling lowlands, but the middle part of the formation forms elongate ridges with relief of about 80 feet. In the area of Five Forks, the Elbrook is closely folded and the terrain is, therefore, a series of small narrow ridges and valleys. To the north, between Jugtown and Guilford, the relief diminishes considerably.

The basal portion of the Elbrook is composed of 100 feet of pure, dark massive limestone. The contact with the underlying Waynesboro Formation is not exposed but it is probable that the relationship is conformable. The remainder of the lower third of the formation is markedly shaly. It is composed of finely laminated, shaly limestone and calcareous yellow- to green and some reddish shale. These beds readily weather into buff-colored, shaly plates, most of which are leached of their calcareous content and are, therefore, somewhat punky.

Exposed rocks of the middle ridge-forming part of the formation are predominantly bluish-gray limestone with subordinate beds of dolomite. Some limestone beds are composed of stromatolites of the cryptozoon type (Sando, 1957, p. 37), and are especially well developed in the road cuts just south of Five Forks, and at Duffield Cave which is 3,000 feet southwest of the intersection of State Highway 997 and Legislative Route 28003, and 4,500 feet south-southwest of Duffield. The 30 feet of rock exposed at Duffield Cave appears to be cyclical commencing with a stromatolite- to oolitic limestone bed that contains floating quartz grains and passes into interlaminated limestone and dolomite. The cycles are from 1 to 3 feet thick. Stose (1909, p. 5) states that at this horizon there are some very siliceous, quartzitic limestones which weather to porous slabby sandstone. Apparently the limestones and dolomites and subordinate quartzitic limestones hold up the ridges.

The upper half of the formation, in most of the area, is composed of light-colored calcareous shale and laminated argillaceous limestones. These readily weather into plates of leached shale and underlie valleys relative to the middle ridge-forming part of the Elbrook and the lower ridge-forming part of the Conococheague. There is considerable difficulty in locating the top of the Elbrook Formation in the southeastern part of the area. In Washington Township what was mapped as sandier lowermost Conococheague on the geologic maps of Stose (1909) and Cloos (1951) is included as uppermost Elbrook in this report. These beds underlie a ridge with an immediate relief of 100 feet. The uppermost beds are well exposed in road cuts on State Highway 16 about 1,500 feet west of where it crosses West Branch of Antietam Creek, and consist of 400 feet of interbedded massive dolomitic argillite, siltstone, and dolomite, all in shades of brown and buff with several thin interbeds of red and green argillite. These beds are conformably overlain by bluish-gray limestones of the Conococheague and conformably underlain by bluish-gray limestone of the Elbrook. The ridge formed by these beds is absent at Nicodemus, 2 miles to the north and was not observed anywhere to the north. Disappearance of the ridge is probably due to a change in lithofacies as these resistant beds give way to a sequence of nonresistant blue-gray limestones and limy buff shales somewhat similar in appearance to the Conococheague. Discriminating between the Elbrook and Conococheague, north of Washington Township, is difficult in areas of fair or poor outcrop. The change in slope from the hills of the

Conococheague to the valleys of Elbrook, increase in amount of shale float and shale chips in the soil, and decrease in number of outcropping limestone ledges are some of the criteria that have been used to map the contact.

Well-developed, cryptozoon-stromatolite bioherms in the upper beds of the Elbrook are exposed in the Western Maryland Railroad cuts at Guilford, 3,800 feet north and slightly east of Grindstone Hill. This exposure is particularly impressive because the beds are horizontal, being located on an anticlinal crest (Figure 3). Several different forms of cryptozoon are present within an individual bioherm, and in instances some of the bioherms are as much as 10 feet wide and 5 feet high. These pass abruptly into inter-reef limestones composed of banded mechanical (Sando, 1957, p. 33) limestones with crenulated buff argillaceous partings (Figure 4). The original mound-like character of the bioherm is shown by beds pinching out against the mounds and arching over the mounds (Figure 4). In Figure 4, the dark uppermost bed is a brownish-buff dolomite with clasts of blue limestone and floating grains of spherical, well-rounded quartz sand, perhaps of eolian origin. Local unconformities and abrupt pinch-out of conglomeratic limestones are also present. All evidences indicate deposition in a littoral environment for the limestones and probably a supralittoral environment for the dolomite beds.

Lack of outcrop and structural complexity do not permit an accurate determination of the thickness of the Elbrook Formation. In northern and southern Maryland, Bassler (1919, p. 72) determined a thickness of 3,000 feet. Cloos (1951, p. 44) was unable to determine the thickness of the Elbrook Formation in Washington County, Maryland. In Franklin County, Stose (1909, p. 5) calculated an approximate thickness of 3,000 feet west of Quincy. This figure is accepted for the present, but may be in considerable error.

A sparse, partially preserved trilobite fauna collected by Stose (1909, p. 6) suggests a Middle Cambrian age. The fossils were collected from pure limestones at the base of the formation in a quarry east of Waynesboro.

Conococheague Group

The term Conococheague was first used by Stose (1908, p. 701) in a formational sense for a series of dark-blue banded limestones and subordinate dolomites that are abundant in Franklin County. The formation derived its name from Conococheague Creek just northeast of Chambersburg where these rocks are excellently exposed. The formation is elevated to group status in this report.

Rocks of this group form a broad belt through the center of the mapped area. On the Pennsylvania State Line the Conococheague forms

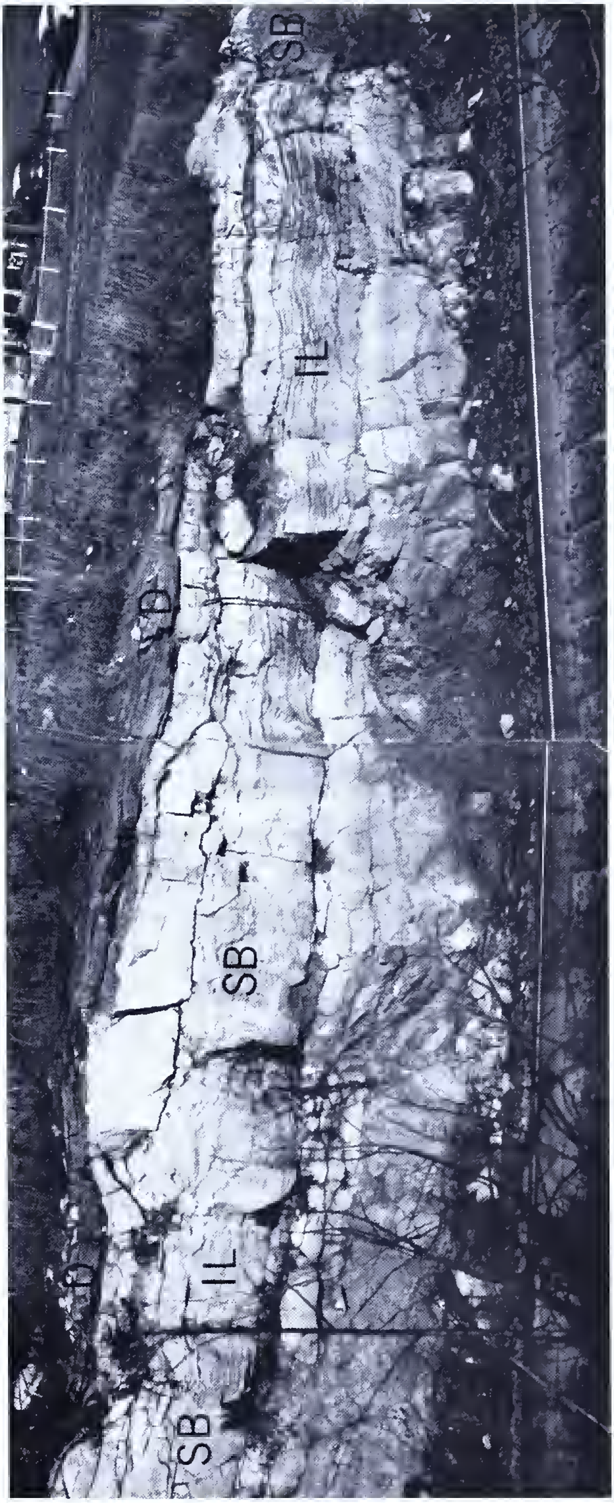


Figure 3. Stromatolite bioherm complex developed in the upper part of the Elbrook Formation at the Western Maryland Railroad cut near Guilford. Note the large limestone stromatolite bioherms (SB), laminated inter-reef limestone (IL), and overlapping bed of arenaceous dolomite (D).

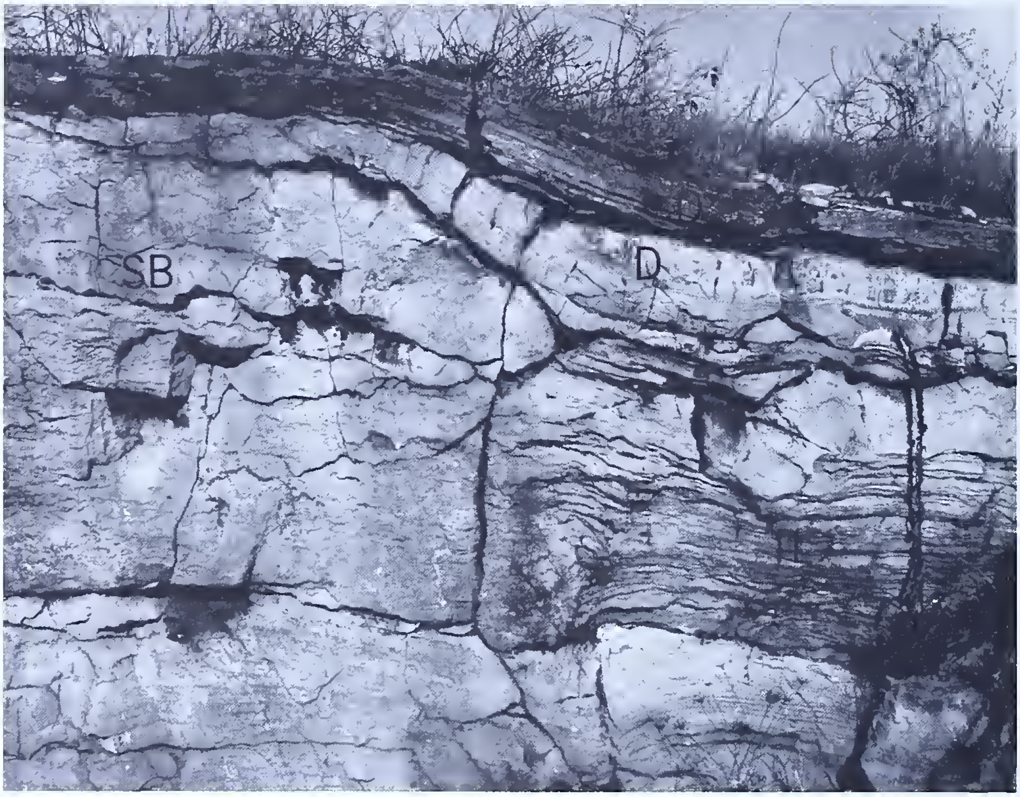


Figure 4. Closeup of Figure 3 to demonstrate intertonguing of stromotolite bioherm (SB) ond lominoted inter-reef limestone (IL). Note thinning ond orching of dolomite beds (D) over the originol mound-like bioherm.

a belt 6 miles wide; however, at the northern limit of mapping the outcrop belt is slightly more than 1 mile wide. Within this broad belt folding and faulting combine to form a complex pattern of Conococheague distribution. The rocks are more resistant than the overlying limestones to the east and form rolling ridges with as much as 100 feet of local relief.

Previous workers in Franklin County did not map subdivisions of the Conococheague. It was considered a formation by Stose (1909), Bassler (1919), and Cloos (1951), although they all observed significant lithologic variations within the unit. The basal few hundred feet of the Conococheague were considered as a distinct member in western Maryland by Wilson (1952, p. 307). This unit was named the Big Spring Station Member of the Conococheague Formation. According to Wilson (1952, p. 307) the Big Spring Station Member at the type section is defined by abundant beds of shaly, yellow-weathering dolomitic siltstone or silty dolomite and coarsely arenaceous dolomite or siliceous orthoquartzite. The sandstones support a wooded ridge where they crop out.

It is difficult to carry the Big Spring Member east across the Cumberland Valley to the area of this study. Apparently the amount of silty dolomite and quartzitic sandstone decreases significantly. In the section that Wilson (1952, p. 312) measured 2 miles south of Waynesboro and referred to the Big Spring Station Member there are only five sandstone beds each averaging about 1 foot in thickness in the 240 foot interval. There are also only three massive beds of shaly dolomite in this interval. Nearly all of this member is composed of laminated and massive limestone with subordinate laminated dolomite.

At Waynecastle Dairy, Wilson (1952, p. 314) found only two medium thick sandstones in the 120 feet he referred to the Big Spring Station Member. From his general description there is little of objective lithologic character to differentiate the Big Spring Station from the rest of the Conococheague. The section at Waynecastle Dairy was also measured by this writer (Root, 1964, p. 157) and the term Big Spring Station Member was used then. However, it is now concluded, on the basis of subsequent expanded mapping, that the Big Spring Station is not a mappable unit in Franklin County, because except for the few thin sandstones which are probably local, there is no significant lithologic difference from the overlying Conococheague. There are five thin sandstone or highly arenaceous carbonate beds in the Conococheague, above what was termed the Big Spring Station indicating that the occurrence of sandstone is not a definite criterion. In addition there is no single ridge-forming unit marking the basal Conococheague, but only a general, more elevated and rugged terrain that contrasts with the easily eroded shaly limestones of the Elbrook.

On a regional consideration it is to be expected that the Big Spring Station sandstones should pinch out to the east because general eastward and southeastward disappearance of Upper Cambrian clastics and dolomites has been demonstrated by many workers.

In the Womelsdorf quadrangle, Lebanon County, Geyer (1963, p. 29) assigned group status to the Conococheague dividing it into the Snitz Creek, Schaefferstown, Millbach, and Richland Formations, listed in ascending order. In Franklin County the Conococheague, which was formerly considered as a formation, is divisible into two units which have been traced by reconnaissance to within 2 miles of Mechanicsburg in Cumberland County. On the basis of the lateral persistence of these two mappable units the Conococheague is also raised to the status of a group composed of the Zullinger Formation at the base and the Shadygrove Formation at the top, both named herein.

Zullinger Formation

The type section of the Zullinger Formation is in the road cuts at Waynecastle on State Highway 16, 3 miles west of Waynesboro. This section has been measured by Wilson (1952) and Root (1964) and is presented in the Appendix, locality 1. The formational name which is derived from the town of Zullinger 1 mile to the east is selected instead of the more appropriate name of Waynecastle because of possible confusion with the Waynesboro Formation.

The Zullinger Formation overlies the Elbrook Formation with apparent conformity and is lithologically gradational with it although nowhere is the contact well exposed. The break in slope and appearance of shaly limestone interbeds marks the top of the Elbrook. As mentioned previously, near Waynesboro and to the south, the uppermost Elbrook forms a ridge whereas in most of the county the uppermost Elbrook underlies a valley adjacent to the Zullinger limestone ridges.

The Zullinger Formation is composed of blue-gray limestone frequently interbedded within dark blue-gray dolomite. This formation is what all previous writers have considered to be typical Conococheague lithology. It is described in detail in the Appendix.

The basal 115 feet is composed of 3 to 4 foot thick beds of interbanded limestone and dolomite with subordinate interbeds of mechanical and algal limestone. Above this are 5 feet of sandy dolomite and 87 feet of algal and minor mechanical limestone. Algal pipes and clastic filled channels of the type shown by Sando (1957, Pl. 7, Fig. 2) are prominent. This is succeeded by 73 feet of limestones of the algal and mechanical types, some limestones sparsely laminated with dolomite. Five beds of limy sandstone to sandy limestone occur in the upper half of this unit and probably represent the limited eastward extension of what is the Big Spring Station Member on the western side of the Great Valley. All these beds aggregate to 280 feet in thickness. There is no outcrop below these beds, and the Conococheague-Elbrook contact is selected where the outcrop ends, which also coincides with the break in slope. It is conceivable the lowermost 115 feet which is only 50 percent exposed could be the Elbrook, although there is no leached shale float to indicate so. Again this illustrates the problems inherent in selecting a mappable boundary between two units with a lithologically transitional boundary.

Above this lower portion is an interval 275 feet thick with essentially no outcrop, except for a zone with about 25 feet of limy laminated dolomite, mechanical limestone with secondary dolomite patches, and a 1-foot bed of medium-grained, well-sorted, calcareous sandstone.

This is succeeded by the main body of the Zullinger limestones, which is at least 1,550 feet thick. This sequence is composed of cyclically deposited carbonates which have been described in detail by Root (1964). In the course of measuring this portion of the rock sequence it was apparent that several distinct lithologies, averaging 2 to 5 feet in thickness, are repeated.

Rock type 1 is intraformational limestone conglomerate. In this rock type are included both edgewise and flat-bedded conglomerates. The rock consists of pebbles of limestone, less frequently dolomite, discoidal in shape with rounded edges, usually ½ to 1 inch long and clearly derived from the underlying or adjacent beds. The clasts are set in a micrite matrix admixed with varied amounts of calcarenitic and oolitic components. This unit is frequently disconformable on the underlying unit (Figure 5).

Rock type 2 is a complex of mechanical, stromatolitic, and oolitic limestones. The detrital limestone grains may be of organic or of inorganic origin. They seldom range above coarse-sand size and are set in a micrite matrix. The few coquinoidal beds present are included here also.

The stromatolites are mostly of cryptozoon forms, both cabbage head and sheet varieties.

Also included in this category are oolitic limestones. The oolites, which show both concentric and radial structure, are well sorted attaining a maximum size of 1 to 2 mm. Tectonic processes have elongated the oolites to some degree although this is not readily apparent in outcrop. They are set in a micrite cement.

The mechanical, stromatolitic, and oolitic limestone are all intimately associated (Figure 5). Few beds are composed entirely of a single lithology; an admixture or intercalation of the above lithologies is characteristic of this unit.

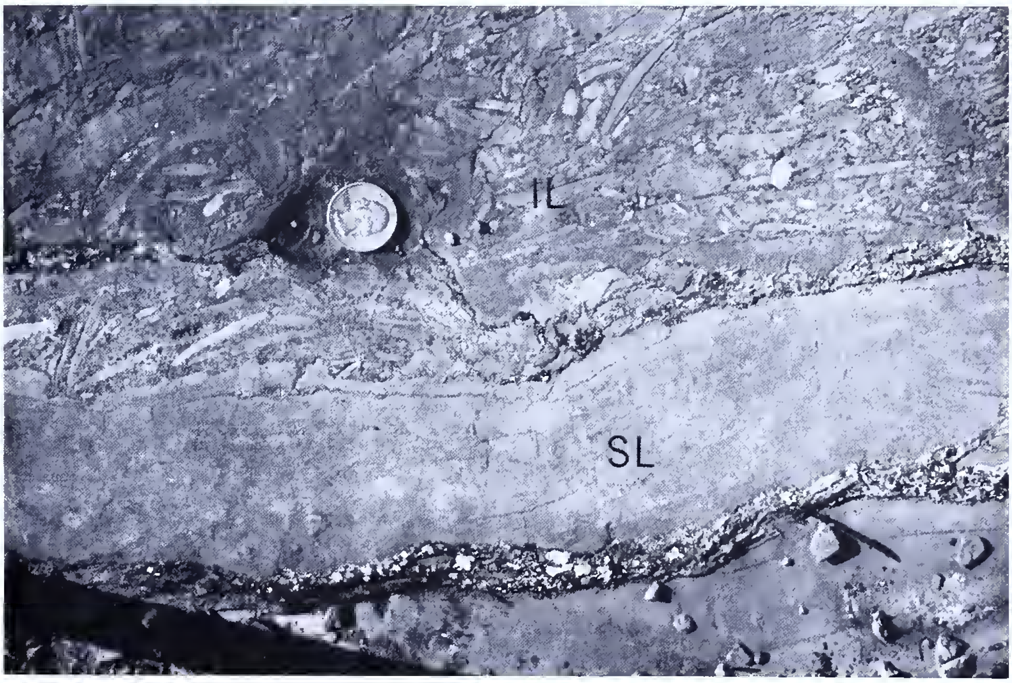


Figure 5. Cyclical limestones of the Zullinger Formation. Intraformational limestone conglomerate (IL) overlies stromatolite limestone (SL). These correspond to rock types 1 and 2 of Figure 8 and the text.

Rock type 3 consists of limestone interbanded with dolomite. The limestone bands which compose 60 to 70 percent of this rock type are usually ½ to 1 inch thick. Internally the bands may be finely laminated, structureless micritic, or finely clastic. The bands are wavy, imparting a ripple-marked aspect. The silty dolomite is in bands about a quarter of an inch thick and characteristically supports lichen growth. The contrast between the medium-gray limestone and the silty buff dolomite forms a distinctive banding. Occasionally there are intercalations up to 6 inches thick of rock types 1 and 2 within this sequence (Figure 6).

Rock type 4 consists of limestone interlaminated with dolomite. The limestone laminae which usually compose about 60 percent of this rock are 0.1 to 5 mm thick. The laminae are planar and parallel to bedding although gently undulose and cross-bedded laminae are also present.

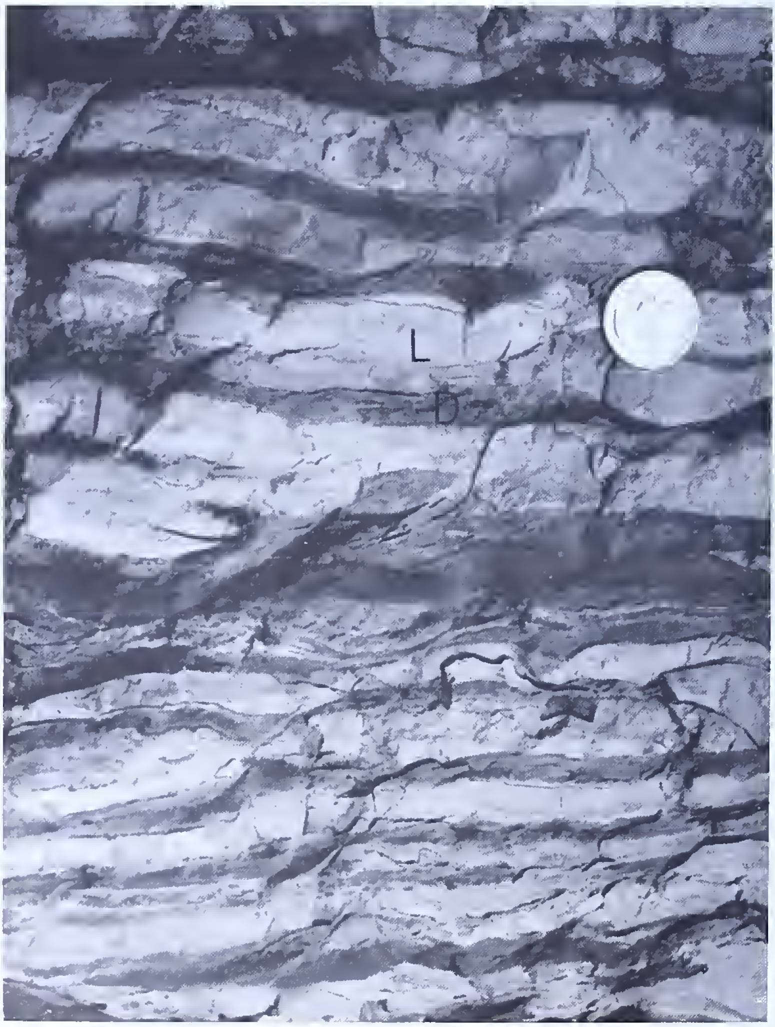


Figure 6. Cyclical carbonates of the Zullinger Formation. These are interbanded limestones (L) and dolomites (D) which comprise rock type 3 of Figure 8 and the text.

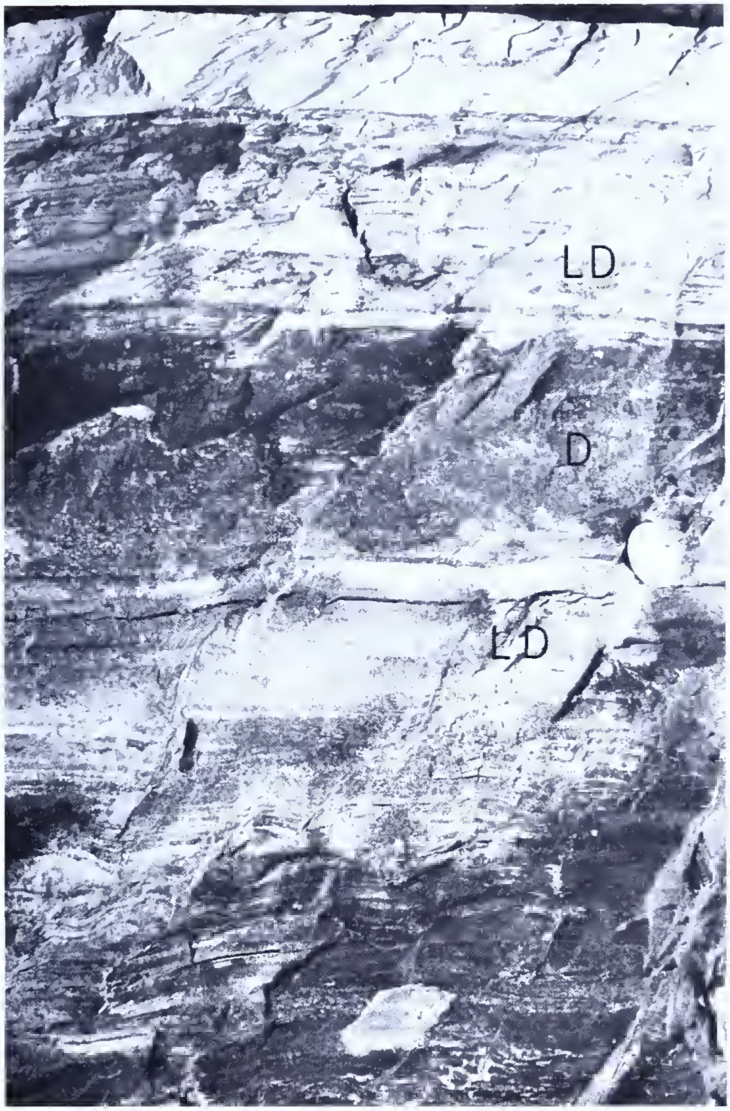


Figure 7. Cyclical carbonates of the Zullinger Formation. Shown here are the interlaminated limestones and dolomites (LD) of rock type 4 which underlie and overlie a thin dolomite bed (D) of rock type 5. Refer to Figure 8.

The limestone alternates with dolomite of similar thickness and fabric but which is finely crystalline, buff-colored, silty, and weathers in relief relative to the medium-gray limestone laminae (Figure 7).

Rock type 5 consists of thin dolomite beds that characteristically weather to buff tones in contrast to most of the limestones which weather light to medium gray and are medium to light gray on fresh surfaces. The dolomite is uniformly finely crystalline throughout and harder than adjacent limestones. The dolomite beds are generally structureless but occasionally show some internal laminations due to variations in crystal size (Figure 7).

Silt-size quartz and clay are more abundant in the dolomite than the limestone. Floating sand-size quartz grains occur in some of the dolomites, and several thin sandstone beds composed of medium to coarse grained, rounded, well-sorted quartz grains are intimately associated with the dolomite beds.

The dolomite of this rock type and types 3 and 4, because of their texture and structure, are considered as either primary or penecontemporaneous dolomites.

There are slight variations of other types but almost all the carbonates can be classified in these major categories which occur repeatedly throughout this part of the stratigraphic sequence. Types 1 and 2 are most abundant, occurring more than 40 times. Types 3 and 4 are less abundant, and type 5 is least abundant occurring about 20 times. The relation of these rock types to each other at first was not apparent because no obvious pattern exists. After some study, however, it was concluded that the rock types are part of a simple depositional cycle initiated by rock type 1 and 2 (Figure 8), and are sequential to each other. Forty-three cycles, of varying degrees of development, are exposed at the measured section.

This ideal cycle occurs in several places in the Conococheague at Waynecastle Dairy. However, there are numerous places where part of a cycle develops or where the cycle develops but one or more of the rock types is absent. Because of the geologic factors controlling the rock sequence, it is to be expected that development of the ideal cycle would

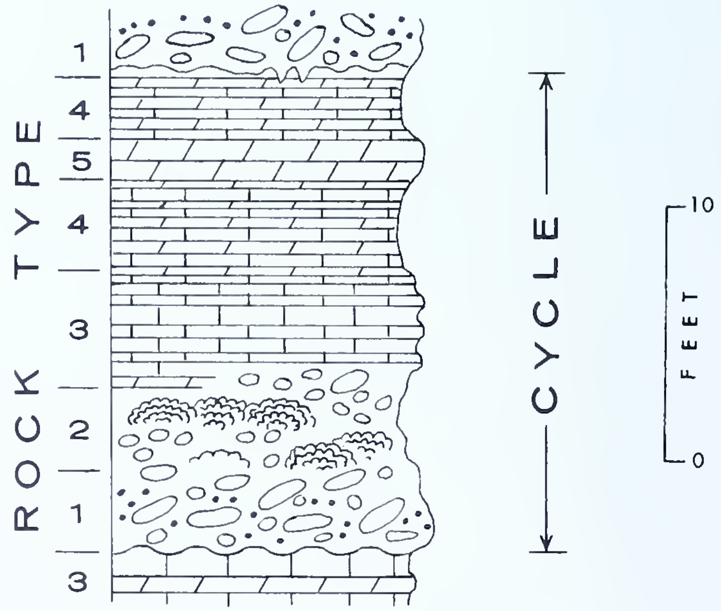


Figure 8. Idealized rock succession within a sedimentary cycle in the Zullinger Formation. Refer to the text for an explanation of the rock types.

be rare. Wave action which exerts considerable control upon the formation of the high mechanical-energy rock types 1 and 2 would be affected by any shift in strand line or by periods of variable storm intensity. Geochemical conditions, in large part, control the formation of low mechanical-energy sediment rock types 3, 4, and 5. Changes in such factors as temperature, pressure, pH, ionic concentration, etc. could affect the type and amount of carbonate being precipitated. Thus the dependence of the rock sequence in the cycle upon both mechanical energy and chemical conditions, partly independent factors, explains the paucity of complete cycles in the section. Age equivalent rocks throughout the State also show cyclical carbonate patterns indicating (Root, 1964) that a single factor of regional extent is the controlling mechanism. An oscillatory onlap-offlap system due to either rhythmic crustal movements or eustatic sea level changes is the most plausible explanation.

The total thickness of the Zullinger Formation measured at Waynecastle is approximately 2,100 feet. The top of this unit is not exposed because the uppermost beds pass into a synclinal axis. From consideration of the structural elements in which this section was measured, it appears that there are at least several hundred feet of additional Zullinger beds above the highest beds present at the Waynecastle section. Probably 2,500 feet might be a reasonable thickness.

Trilobites collected by Wilson (1952) indicate that the Zullinger Formation contains late Dresbachian Stage to medial Trempealeauian Stage elements. The Zullinger Formation generally has a sparse fauna; much of it being destroyed by recrystallization of the rock texture or by tectonic deformation.

Shadygrove Formation

The name Shadygrove Formation, from the community of that name, is here applied to the relatively pure carbonate beds forming the uppermost part of the Conococheague Group. Previous workers have recognized the presence of this unit but did not separate it. Stose (1906, p. 6) recorded dove-colored pure limestone, fine-grained pink marble, and chert from the top of the Conococheague west of Scotland. Bassler (1919, p. 78) recorded 400 feet of pink marbles, light-colored limestone, oolite beds, and yellow chert at the top of the Conococheague near Hagerstown. Cloos (1951, p. 45) states that in Washington County pink marbles and lighter colored limestone appear more frequently toward the top of the Conococheague.

The Shadygrove Formation forms a lowland between the ridge-forming limestones of the underlying Zullinger Formation and overlying Beekmantown Group. Blocks of chert are prominent in the soil and in places are piled up against fences. The contact between the Zullinger and Shadygrove Formation is gradational as there are thick beds of light-colored to pink limestone interbedded with the typical limestones and dolomites of the Zullinger Formation. This relationship is well shown in the outcrops north of Legislative Route 28032 about 0.5 mile northwest of Clay Hill.

The zone of interbedding increases to the south and is several hundred feet thick in the syncline at Wingerton and especially in the small syncline immediately to the east. Exposures along Legislative Route 28028 beginning 1 mile east of Wingerton show the interbedded character of the two lithologies. In this area it is difficult to pick the contact between the Zullinger and Shadygrove Formations. For convenience the base of the Shadygrove is picked at the highest occurrence of ridge-forming limestones and dolomites typical of the Zullinger Formation. It may be that farther south in Maryland the Shadygrove is not a mappable unit. The upper contact with the Stoufferstown Formation of the Beekmantown Group is sharp and easily recognized.

The type section of the Shadygrove Formation is in the farm fields 0.6 mile south and slightly east of the hamlet of Shadygrove on State Highway 16 (Appendix, locality 2). This section also includes 250 feet of the upper part of the Zullinger Formation. On the east the Zullinger beds are cut off by a reverse fault. To the west of this fault the section is essentially vertical to subvertical in dip. Above the 250 feet of Zullinger beds is a covered interval of 280 feet containing the contact between the Zullinger and Shadygrove Formations. However, the first outcrop of Shadygrove limestone indicates that an anticlinal fold occurs in this interval. The fold is of such dimensions that no more than 200 feet of Shadygrove can occur in the covered interval. However, several other minor folds could be present further reducing the amount of Shadygrove represented by this covered interval. The lowest exposed Shadygrove beds consist of 3 feet of light blue-gray dense micritic limestone with a pinkish cast and cut by pink calcite veins. This limestone looks similar to the so called 'vaughanitic' limestones of the St. Paul Group. A covered interval of 44 feet is present above this. This is succeeded by an interval 130 feet thick, with 60 percent exposure, consisting of light gray weathering micritic algal limestone and minor medium thick beds of mechanical-skeletal limestone with muddy gray dolomite laminae and bands. Abundant nodules of blocky fracturing, honey-brown to pinkish-brown, coarsely textured chert occur as float. The pure micritic algal limestones have a slight pinkish cast especially when wet. One of the limestone beds also contains abundant floating quartz grains. Above this is an 80-foot covered interval. Overlying this is about 350 feet of intermittent limestone outcrop. The limestone is principally light blue to gray, very finely mechanical, and with grayish-buff to yellow-orange seams and laminae of dolomite. Among the limestone types are light gray laminated and structureless algal limestone with a pinkish cast, interlaminated limestone and dolomite, and intraformational limestone conglomerate.

The type section of the Shadygrove includes 576 feet of outcrop plus a lower covered interval that could include as much as another 210 feet of section. This would be a total thickness of about 780 feet. However, 3,300 feet due south of Clay Hill School in Antrim Township, a thickness of about 650 feet was computed from width of outcrop and dip of beds in an area of simple homoclinal structure. For purposes of this report the thickness of the Shadygrove Formation will be considered as about 650 feet.

In West Virginia, Donaldson and Page (1963, p. 164) measured a complete Conococheague section 2,200 feet thick. In that area the equivalent of the Zullinger Formation is 1,800 feet thick, and includes 220 feet of the Big Spring Station Member that they recognized. The uppermost 400 feet of the Conococheague which consist of aphanitic limestone, dolomite, and chert may be the equivalent of the Shadygrove Formation.

The Shadygrove Formation includes saukid trilobites of the Trempealeauian Stage. Wilson (1952, p. 315, 316) and Sando (1958, p. 841) collected Trempealeauian faunas from several localities in Franklin County. For convenience, the Cambrian-Ordovician boundary was placed at the base of the Stoufferstown (top of the Shadygrove as used in this report) by Sando (1958, p. 841) although the boundary may be lower by as much as 300 feet.

ORDOVICIAN SYSTEM

Beekmantown Group

The term "Beekmantown" was proposed by Clarke and Schuchert (1899, p. 877) for fossiliferous exposures near Beekmantown, New York to replace the earlier term "Calciferous sandrock". Stose (1909, p. 6) introduced Beekmantown into the Cumberland Valley. He separated the Stonehenge Limestone, a basal member composed of siliceous-banded beds and large edgewise conglomerates, from the upper part of the Beekmantown. In Maryland, adjacent to Franklin County, Sando (1956 and 1957), in an excellent study, raised the Beekmantown to group status composed of a basal Stonehenge Limestone, middle Rockdale Run Formation, and upper Pinesburg Station Dolomite. A member, the Stoufferstown, was differentiated at the base of the Stonehenge Formation by Sando (1958) on the basis of work done at Chambersburg. The Stoufferstown was originally the uppermost part of the undivided Conococheague but by including it in the Beekmantown Sando (1958, p. 841) was able to place the Cambrian-Ordovician boundary at the base of the Stoufferstown, without compromising the mappability of the rock units.

Beekmantown nomenclature in Franklin County follows the usage of Sando. A modification has been made in this report in that the Stoufferstown is raised in status from a member of the Stonehenge Formation to a separate formation. This division preserves the limits of the Stonehenge as originally defined by Stose (1909) while placing the Stoufferstown beds into the Beekmantown Group as indicated by Sando (1958). It is felt that formational status is appropriate because the Stoufferstown is a laterally persistent unit. The writer has readily mapped it as far north as Pinola, 8 miles north of Chambersburg. Sando (personal communication) has traced the Stoufferstown almost to Winchester, Virginia. In this report the Beekmantown Group is composed of four formations listed in ascending order as the Stoufferstown Formation, Stonehenge Limestone, Rockdale Run, and Pinesburg Station Formations.

The Beekmantown Group enters from Maryland in a belt about 4 miles wide centered at Middleburg. From here it trends northeast and is about 1½ miles wide north of Marion. The belt is constricted to a width of less than a mile at Kauffman. The western outcrop border is straight as this is usually a faulted contact, but the eastern outcrop border is sinuous as the Beekmantown is involved in a series of complex folds.

The Beekmantown Group is of Lower Early Ordovician age. The most recent and detailed work on the Beekmantown age is that of Sando (1957, 1958) and most comments in this section are based on these works. He did not divide the Stoufferstown or Stonehenge Formations into formal zones. The Rockdale Run was divided into four normal zones which in ascending order are the *Lecanospira* zone, *Archeoscyphia* zone, *Diparelasma* zone, and *Syntrophopsis-Clelandoceros* zone. The Pinesburg Station is devoid of fossils.

From the Stoufferstown the writer has collected *Finkelnburgia*, and the trilobite *Bellefontia* also was collected at several places in the county. *Lecanospira* and *Ophileta* were present in the lower part of the Rockdale Run Formation. All these species were recorded by Sando (1957, 1958) from Maryland and at Chambersburg.

The thickness of the Beekmantown Group in Franklin County is similar to that recorded to the south. In West Virginia, Donaldson and Page (1963, p. 167) measured a thickness 4,070 feet. In Maryland, Sando (1957, p. 18) recorded a thickness of 3,600 feet but this did not include the Stoufferstown which he did not recognize at that time. As the Stoufferstown is probably at least 200 feet thick the total Beekmantown thickness should be on the order of 3,800 feet. At Chambersburg, Sando (1958) calculated a partial thickness of about 3,500 feet of Beekmantown strata from a series of compromise sections. The top [illegible] Rockdale Run and Pinesburg Station are faulted out. As the Pinesburg Station Member may be as much as 400 feet thick, the actual total thickness of the Beekmantown in Franklin County may be as much as 4,000 feet thick.

Stoufferstown Formation

The Stoufferstown was named by Sando (1958, p. 839) for exposures 1,500 feet north of U. S. Highway 30 at Stoufferstown. As the town of Stoufferstown has merged with Chambersburg, it is best defined as being 12,000 feet east of the center of Chambersburg on U. S. Highway 30.

The Stoufferstown Formation is readily mapped both on the basis of its topographic form and distinctive lithology. It forms a continuous narrow ridge that contrasts with the flat valleys formed by the underlying Shadygrove Formation and the rolling valleys formed by the Stonehenge Formation. The contact with the Shadygrove is sharp but the contact with the Stonehenge is gradationally interbedded.

A good description of the Stoufferstown Formation is given by Sando (1958, p. 840). He refers to this as the coarse-grained lithofacies relative to the Stonehenge, and states:

> The coarse grained lithofacies is composed dominantly of carbonate detritus with particles ranging from clay to cobble size, tabular limestone fragments commonly 2-3 inches in diameter characterize this facies. Many beds are oolitic. The yellowish weathering seams have a high terrigenous quartz content and in places are reinforced by secondary silica so that in many places they weather in sharp relief. Bright-orange weathering patches of dolomite half an inch or less in diameter are a distinctive feature.

The yellowish weathering siliceous seams to which Sando refers are important in the recognition of the Stoufferstown; however, they are frequently dark gray to black in color. They form a distinctive lithology (Figure 9) as well as underlie the ridges. Where they do not outcrop, they form a surficial soil composed of dark colored, hard shaly chips. These seams also sparsely occur near the top of the Zullinger and Stonehenge Formations, but here they are not intimately associated with intraformational conglomerate, especially the edgewise conglomerates so typical of the Stoufferstown Formation.

A section of the Stoufferstown was measured as a continuation of the type section of the Shadygrove Formation (Appendix, locality 2). The thickness of the Stoufferstown here is 261 feet. Near Chambersburg, the type section of the Stoufferstown is about 220 feet thick (Sando, 1958, p. 847). In West Virginia, Donaldson and Page (1963, p. 168) state that the Stoufferstown is 100 to 200 feet thick.

Stonehenge Formation

The term Stonehenge Limestone was used by Stose (1908, p. 703) to designate the basal member of the Beekmantown limestone near the village of Stonehenge at the eastern limits of Chambersburg. Sando (1956, p. 935) raised the Stonehenge to the formation rank and raised the [illegible] to group rank.

The Stonehenge Formation generally forms low rolling valleys. The upper part of the formation is usually more resistant and underlies a subdued ridge. This ridge, between valley-forming limestones of the

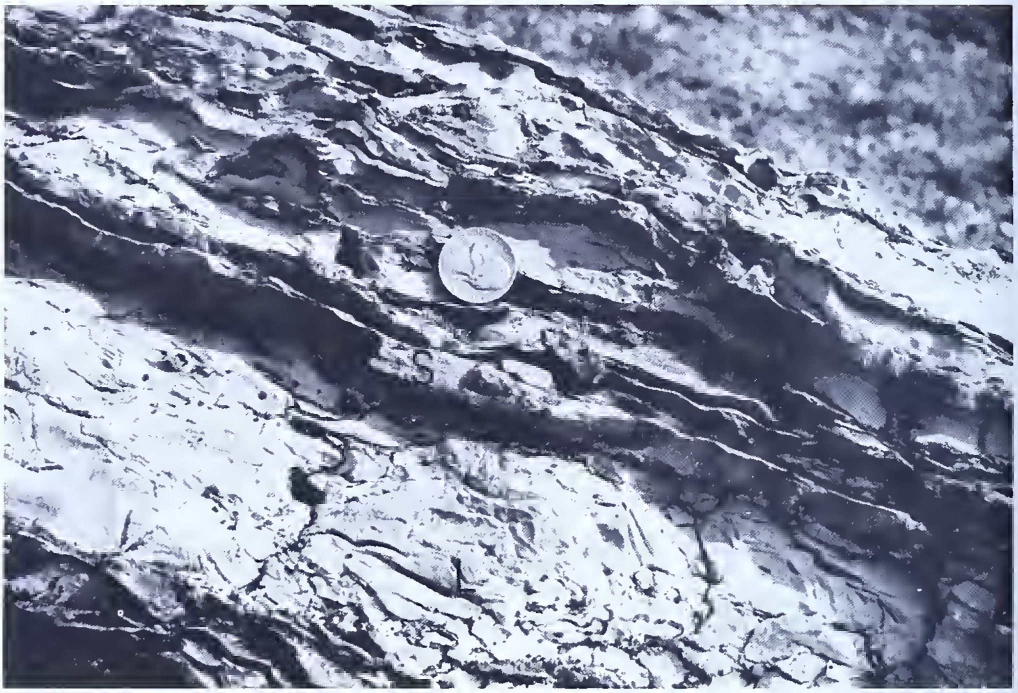


Figure 9. Irregular dark colored praminent siliceaus seams (S) and edgewise limestone conglomerates (L) typical of the Staufferstawn Farmatian.

lowermost Rockdale Run Formation and the less resistant limestones below it, can be of considerable aid in mapping structures.

In Maryland, Sando (1957, p. 17) informally divided the Stonehenge into a lower fine-grained limestone, thick bedded, with abundant gymnosolenid stromatolites which in many places make up biohermal masses, and an upper member of thin-bedded silty mechanical limestone. This informal subdivision cannot be carried into Pennsylvania and was not recognized by Sando (1958, p. 839) at Chambersburg.

The writer did not measure a complete section of the Stonehenge Formation because in no place was there sufficient exposure or structural simplicity to permit this. The sections at Chambersburg measured by Sando (1958) are also not well exposed but serve to illustrate the general lithology here. From various exposures throughout the area of this report the writer has constructed a composite lithologic section of the Stonehenge aggregating some 775 feet in thickness. The composite Stonehenge section is divisible into four informal units whose persistence may be limited.

At the base of the Stonehenge Formation is a zone about 100 feet thick composed of fine-grained limestone and algal limestone. The algal limestone, which is most striking, consists of gymnosolenid stromatolites that make up biohermal masses. They are of the type described by Sando (1957, p. 19) where the algal masses are penetrated by highly irregular channels filled with calcarenite derived from adjacent algal colonies. Bedding is massive in the algal horizons with some beds as much as 15 feet thick. This unit is well exposed about 3,000 feet south and slightly east of Clay Hill School and forms prominent ledges in the fields 8,000 feet due west of Shadygrove and about 2,200 feet south of State Highway 16.

Above this and forming most of the Stonehenge are about 500 feet of thin-bedded, fine-grained mechanical limestones. Sando (1957, p. 835) describes this lithofacies as follows:

> The fine grained lithofacies is composed dominantly of carbonate detritus with component particles ranging from clay to sand in size. Ooliths are uncommon in this facies. The yellowish-weathering seams in these rocks are predominantly fine-grained dolomite with subordinate amounts of silt-sized quartz grains; these seams do not commonly stand in sharp relief on a weathered surface.

Most of the extensive Stonehenge exposures exhibit some of this lithology but it is particularly well shown in the outcrops near the Greencastle reservoir and in the syncline near Wingerton.

Overlying this unit is about 75 feet of ridge-forming limestones somewhat similar in appearance to the Stoufferstown Formation. A section (Appendix, locality 3) was measured near Antrim Church (11,000 feet N50°E from center of Greencastle) that included this unit and the uppermost unit of the Stonehenge as well as 400 feet of the lowermost Rockdale Formation. This unit consists of lower beds of intraformational conglomerate which is in part edgewise conglomerate. It is succeeded by about 70 feet of mechanical limestone with subordinate dolomite bands and irregular laminations. Associated with these beds are some dark gray weathering siliceous seams similar to those seams that are common in the Stoufferstown Formation. Indeed this unit can be confused with the Stoufferstown. This unit is well developed on the east flank of the anticline near New Franklin at the north end of the mapped area, at the Antrim Church measured section, and on the anticlinal nose at Canebrake School.

The uppermost unit, about 100 feet thick consists of a 20-foot thick basal horizon of well-developed gymnosolenid stromatolites that make up biohermal masses. Figures 10 and 11 illustrate the lithologic complexity of this horizon. Above this is about 80 feet of gray mechanical limestone with irregular laminae of argillaceous dolomite. This unit is normally not well exposed, underlying valleys in much of its occurrence. However, the lithology just described can be seen to advantage at the Antrim Church section.

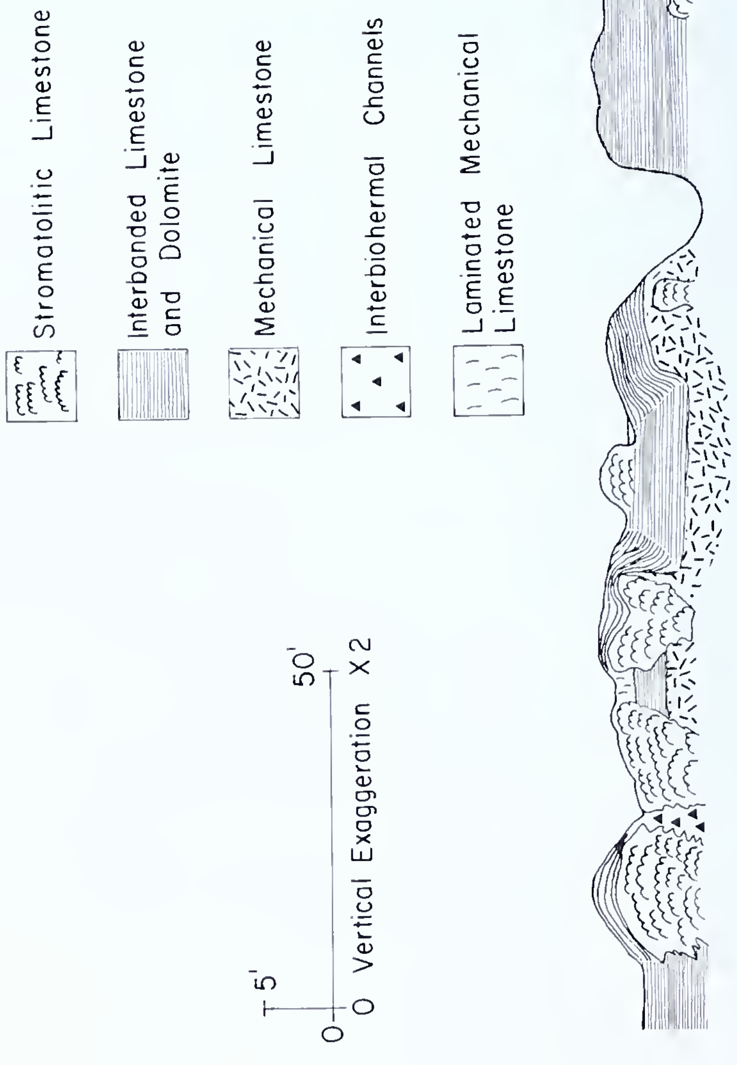

Stromatolitic Limestone
Interbanded Limestone and Dolomite
Mechanical Limestone
Interbiohermal Channels
Laminated Mechanical Limestone
0
5'
0
50'
Vertical Exaggeration X 2

Figure 10. Stromatolite bioherm complex within a single bed near the top of the Stonehenge Formation. This corresponds to unit 19 of measured section No. 3 in appendix.

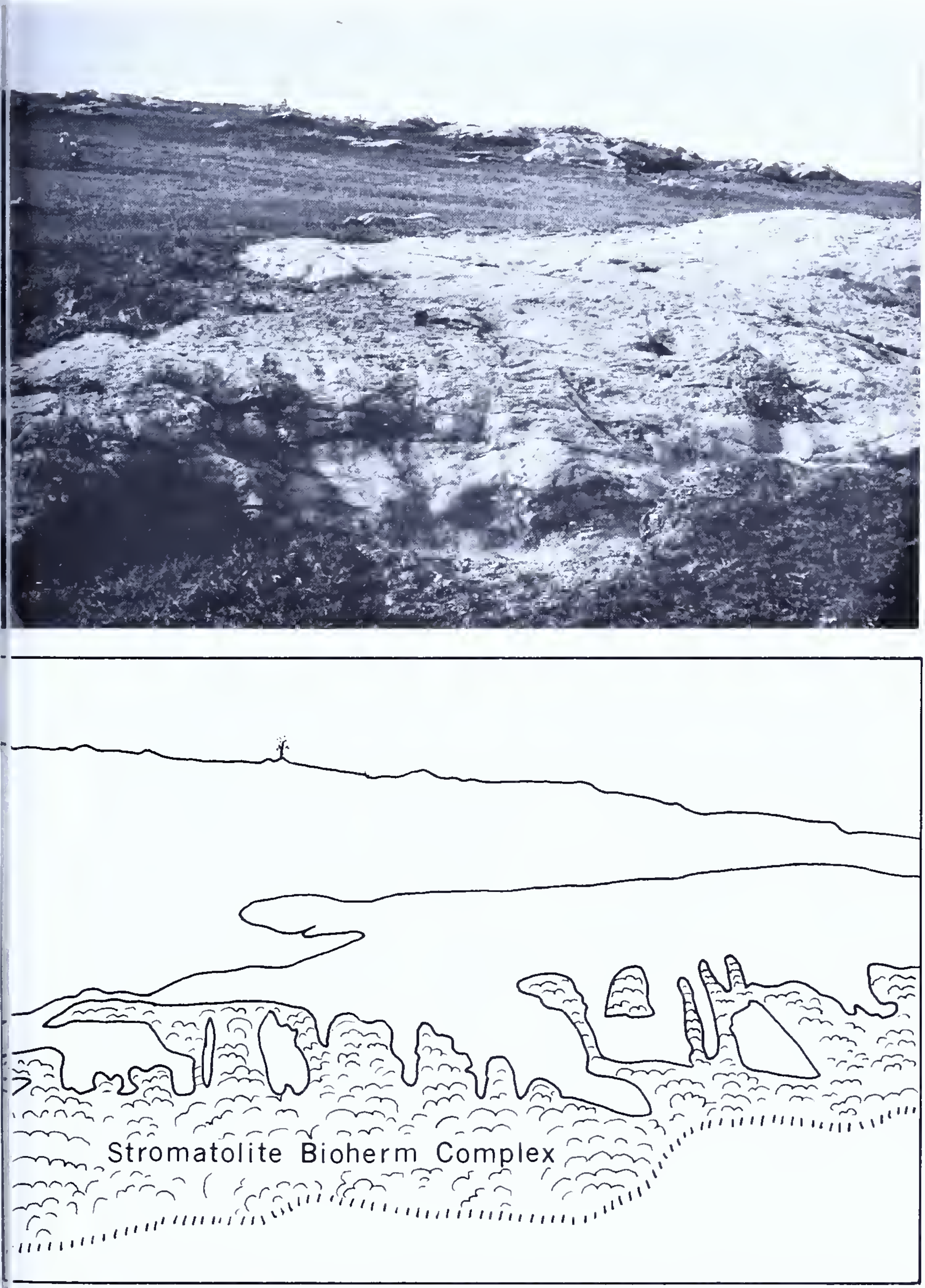


Figure 11. Photograph and interpretative tracing of a portion of Figure 10, Stonehenge Formation, showing complex of gymnosolenid stromatolites forming 'algal pipes' and inter-biohermal channels composed of mechanical bedded limestone.

Rockdale Run Formation

The Rockdale Run Formation was named by Sando (1956, p. 935) for a series of interbedded limestones and dolomites overlying the Stonehenge Formation near Hicksville, Washington County, Maryland. Although the formation contains considerably less dolomite in Franklin County, it is readily referable to the Rockdale Run of Maryland.

Most of the outcrop belt of the Beekmantown Group is composed of the Rockdale Run Formation. Although it underlies low gently rolling terrain, good outcrops are frequent.

Only the lower several hundred feet of the Rockdale Run Formation was measured because structural complexity obscures relations in much of the middle and upper portions of the formation. For a description of these beds near Chambersburg the reader is referred to Sando (1958).

The lower part of the formation forms a distinctive unit in Franklin County, characterized by pinkish marbleoid limestones and chert, and probably should be established as a separate mappable unit.

The section at Antrim Church illustrates the lithology of this lower part of the Rockdale Run Formation (Appendix, locality 3). The base of the Rockdale Run was picked at a 4-foot thick laminated dolomite with subordinate interlaminations of limestones. This is succeeded by 36 feet of limestone, micritic in the lower part but mechanical in the upper part. Above this are the beds that make this lower part so distinctive. They commence with 32 feet of pure micritic cryptozoon stromatolitic limestone with the form of laterally linked hemispheroids (Logan, and others, 1964). Although these limestones are medium light gray the stromatolitic form is outlined by orange dolomitic laminae. Some 3-inch long creamy chert nodules are present at the top of the horizon. Above this is a bed 1 foot thick composed of pink-orange stromatolitic limestones with a marblelike texture and 8-inch long nodules of blocky, creamy to light-honey colored chert (Figure 12). This is succeeded by 350 feet of intermittently exposed pure micritic limestones that are probably stromatolitic in part. Although the limestones are medium gray, at about 6 horizons they are pink or have a pinkish cast when wet. In places they may be confused with the "vaughanites" of the St. Paul Group. Towards the top are several beds of limy dolomite.

The base of this unit may be difficult to select if the dolomite bed is absent but this will result in an error of only about 35 feet in stratigraphic position as the overlying pink micritic limestone and chert are so distinctive. The cherts form a ridge and it is possible to walk along this bed over distances of several thousand feet although the unit as a whole is poorly exposed. In Maryland this unit is not developed and Sando (1957) selected the base of the Rockdale Run on the presence of chert and dolomite.

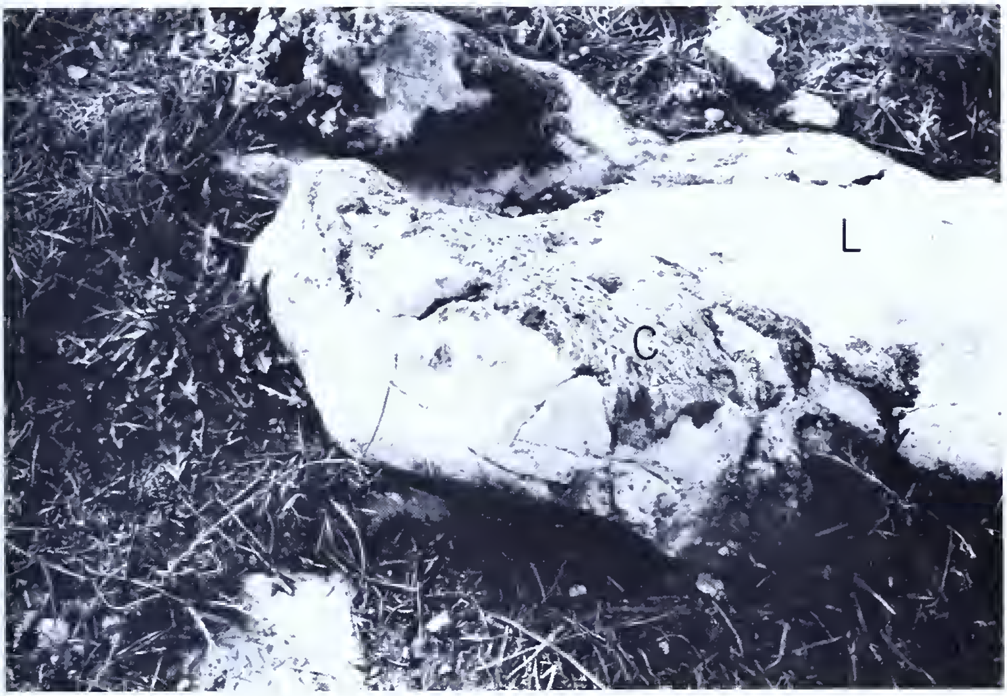


Figure 12. Pink stromatolitic limestone (L) of marbleoid texture with honey colored blocky chert nodule (C). Base of Rockdale Run Formation.

It was not possible to determine the thickness of the lower Rockdale Run unit. The section measured at Antrim Church passes westward into a syncline and then is covered. The total thickness of pure micritic limestones at this section is 420 feet and although the contact with the more typical limestones of the Rockdale Run was not observed, it is probably not more than 600 feet thick.

Beds of the Rockdale Run Formation overlying the algal micrite-chert basal beds are more typical of the Rockdale Run beds described by previous writers in this area. Mechanical and stromatolitic limestones are abundant in the lower half with dolomitic limestones and dolomites becoming interbedded with these lithologies in the upper half. One of the most typical lithologies is a fine-grained mechanical limestone with numerous irregular laminae of dolomite (Figure 13). The aspect of the coarser grained mechanical limestones is shown in Figure 14, and seldom do the clasts exceed the dimensions of those in the photograph. The lithology of the dolomitic limestones and dolomites is shown in Figure 15. The thick dolomite beds are finely laminated and gashed by fractures on the weathered surface.

At the stratigraphic position that corresponds to the top of the Rockdale Run Formation both Stose (1909, p. 7) and Sando (1957, p. 24) report an occurrence of a light colored chert that has been called the rosette chert because of its shape. In the area mapped this chert

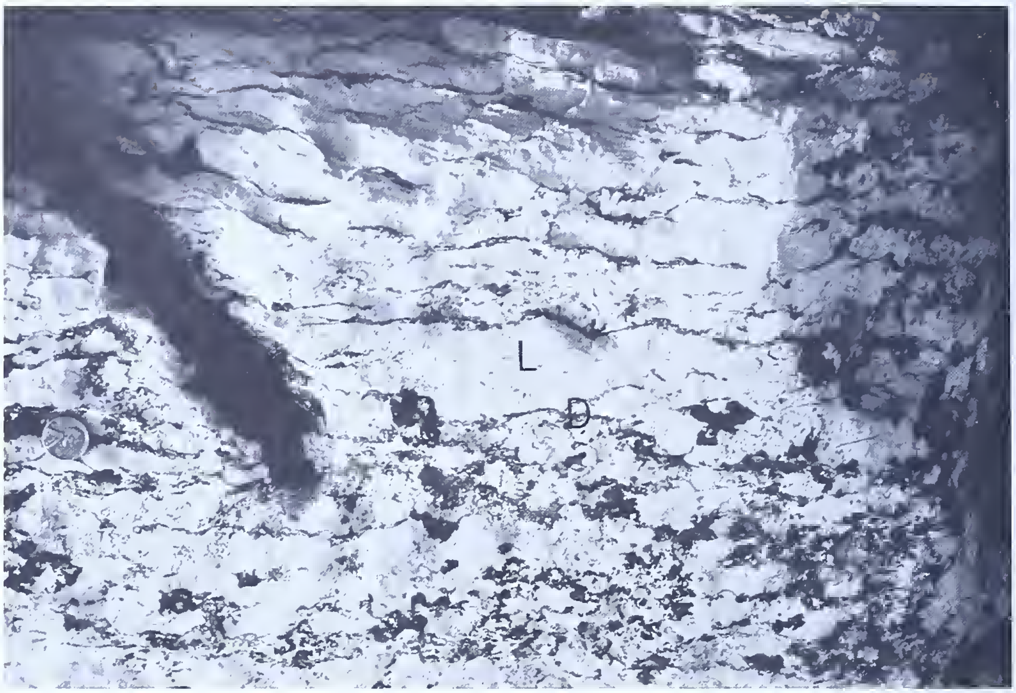


Figure 13. Fine-grained mechanical limestones (L) with crinkly dolomite laminae (D) typical of the Rockdale Run Formation.

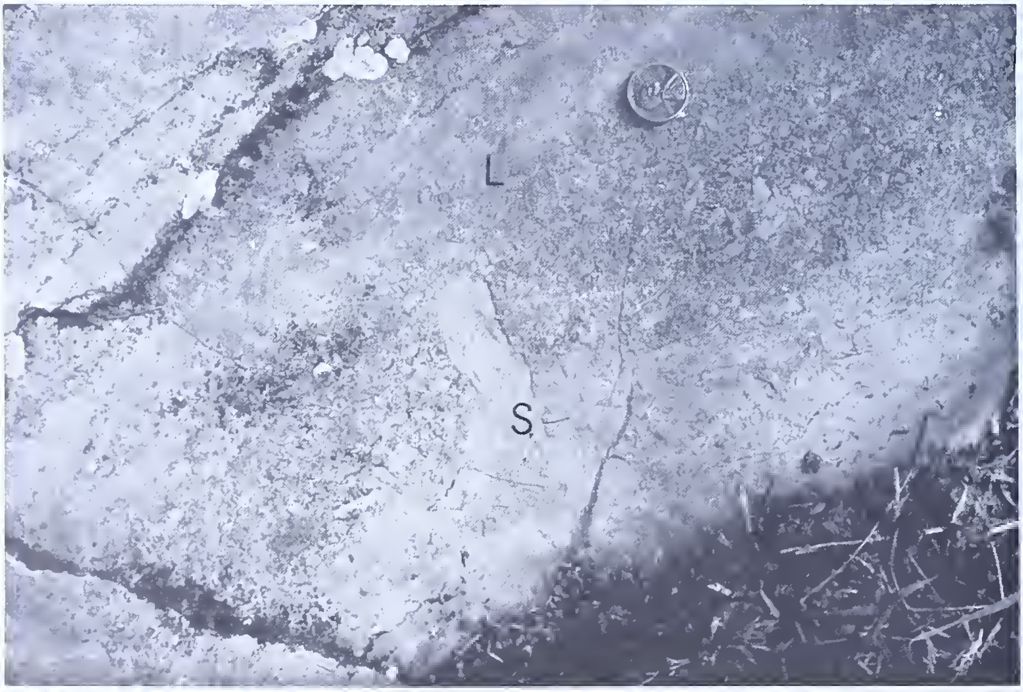


Figure 14. Coarse-grained to finely conglomeratic mechanical limestone (L) and a small stromatolite (S) in growth position, typical of the Rockdale Run Formation.

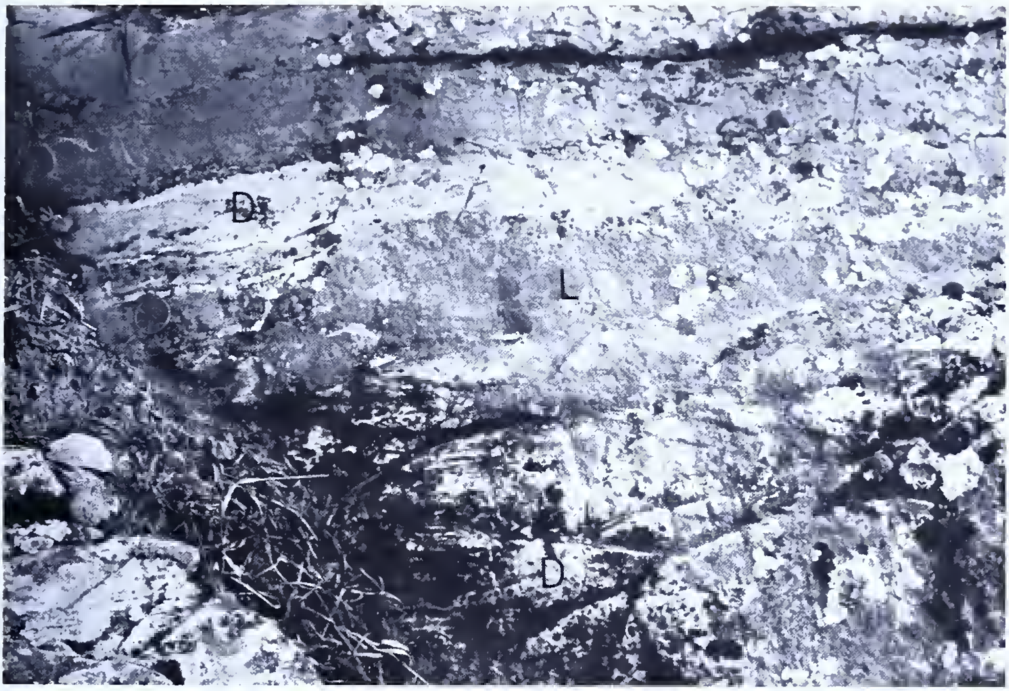


Figure 15. Interbedded dark gray limestone (L) and light gray dolomite and limy dolomite (D) typical of the Rockdale Run Formation. Note mudcracked dolomite band above penny and preferential growth of lichen on the dolomite rather than limestone.

horizon has rarely been seen in outcrop, and only a few pieces have been collected from float at the appropriate horizon.

The thickness of the Rockdale Run Formation is about 2,500 feet thick in Maryland (Sando, 1957, p. 24). In West Virginia, Donaldson and Page (1963, p. 167) measured a section 2,750 feet thick. In Pennsylvania there is no complete section, but Sando (1958, p. 841) measured a partial section 2,550 feet thick at Chambersburg which terminated in the upper beds of the Rockdale Run Formation.

Pinesburg Station Formation

The name Pinesburg Station Dolomite was applied by Sando (1956, p. 936) to a succession of dolomites overlying the Rockdale Run Formation and underlying limestones of the St. Paul Group. The type section is near Pinesburg Station in Washington County, Maryland. Along the Pennsylvania-Maryland border this term can be used within the strict definitions of Sando (1957, p. 28) but north near Kauffman the use of this term may be improper.

Severe faulting and folding cause the Pinesburg Station Formation to occur as a series of small isolated exposures close to the Martinsburg shale. Its topographic expression is indistinguishable from the low rolling terrain of the Rockdale Run, although in Maryland it forms a low ridge because of the contained cherts.

Good exposures of the Pinesburg Station dolomites occur in a belt centered about 4,500 feet due east of Worleytown, Antrim Township. Here the dolomite is medium gray to medium dark gray and weathers yellowish gray to medium light gray. It occurs in beds about 3 feet thick that are distinctively covered with lichen and gashed by numerous fractures (Figure 16). The rock is fine to medium crystalline and typically finely laminated (Figure 17), although some massive and mottled beds are present near the top and bottom of the formation. Nearly 180 feet of Pinesburg Station dolomite is exposed along an unnamed tributary to Muddy Run about 7,000 feet N5°W from the center of Greencastle, but the base of the formation is cut out by faulting. The lithology here is essentially entirely dolomite.

There is a belt of the Pinesburg Station Formation commencing about 6,500 feet west of Marion and continuing south for a distance of about 8,000 feet. Again the base of the section is cut out by faulting. At the south end of this belt about 120 feet of the upper part of the formation is exposed and at the north end about 50 feet is exposed. In both instances there is considerably more limestone present than in the beds at Worleytown. In the section at Kauffman farm, about ten dolomite beds are present in a 300-foot sequence of limestone (Appendix, locality 4).

The apparent increase in the amount of limestone present at the stratigraphic position of the Pinesburg Station dolomite causes difficulty in mapping, especially in the thin belt of dolomite present just south of

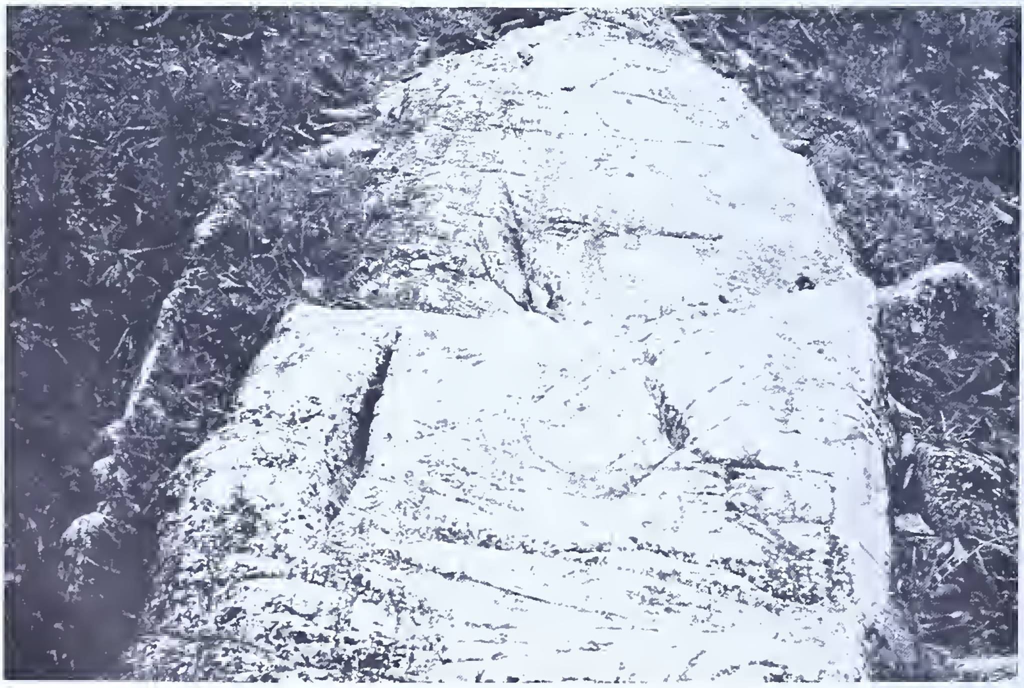


Figure 16. Gashed fractures typically developed in the massive dolomites of the Pinesburg Station Formation.

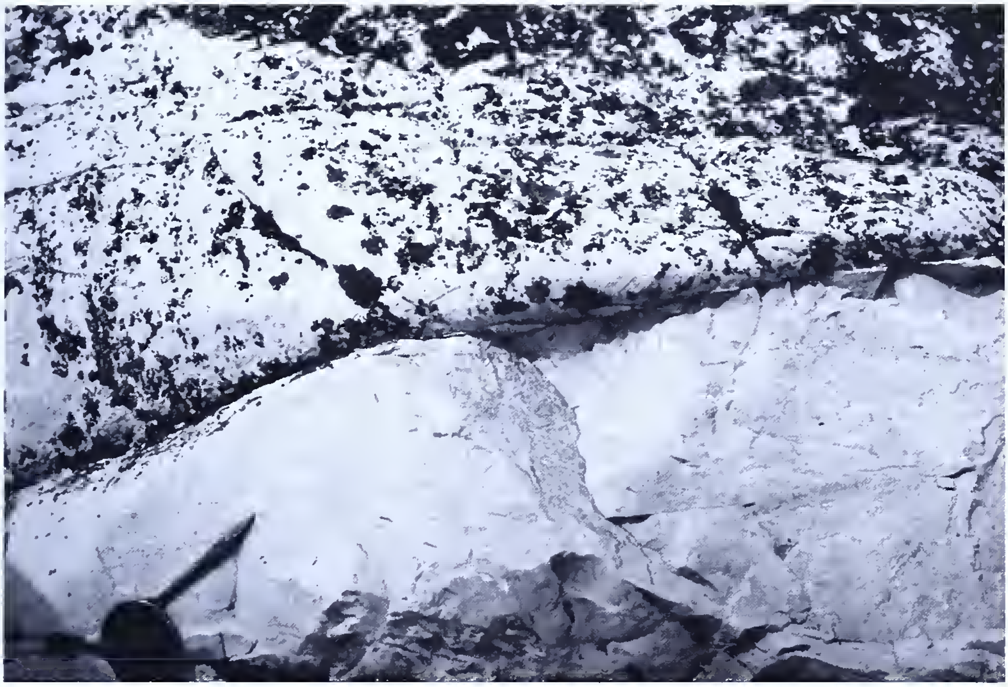


Figure 17. Typical fine laminations and lichen growth on the Pinesburg Station dolomite.

Marion. It cannot be demonstrated conclusively that the beds are actually Pinesburg Station as mapped and not a dolomitic facies within the St. Paul Group. The best outcrops showing this lithology are about 4,500 feet south of Marion near the east-west spur of the Pennsylvania Railroad where over an interval of 100 feet, vertical ledges of light-gray finely banded dolomite and subordinate ledges of mottled blue limestone occur.

If the increase in amount of limestone at the stratigraphic position of the Pinesburg Station Formation continues to the north then this formational name should be dropped. Sando (1957, p. 28) and Neuman (1951, p. 278) placed the upper limit of the formation at the base of the lowest limestone, and the former demonstrated the intertonguing of limestone and dolomite over a 60-foot interval at the base of the St. Paul Group. In keeping with the strict definition of Sando it might be best in future work, to consider these dolomites and subordinate limestones in the northern half of Franklin County as a unit within the St. Paul Group.

Thicknesses ranging from 380 to 500 feet were measured by Sando (1957, p. 28) in the western part of Washington County, Maryland, but in the eastern part of the county a thickness of 500 feet was indicated from width of outcrop. In the mapped area the thickness recorded at Worleytown is 450 feet but this includes some limestones in the lower half of the formation. This lower portion is included with the upper part because dolomites as a whole are so sparse in the Rockdale Run Formation in Franklin County that it is more natural to consider these beds with the Pinesburg Station Formation. Mapping is facilitated also by including these beds. The thickness is only about 260 feet (Figure 18) when only the upper exclusively dolomitic part is considered.

St. Paul Group

Limestones of the St. Paul Group are the best understood units in the Great Valley because of their economic importance in West Virginia and Virginia. This group was originally termed the Stones River Limestone by Stose (1909, p. 10) because he thought these rocks were the extension of the Stones River Limestone in Tennessee. Subsequent studies by Cooper and Cooper (1946) and by Neuman (1951) have shown that the term Stones River is not applicable in the Great Valley. In this report these beds have been assigned to the St. Paul Group following Neuman (1951) who divided it into lower Row Park and upper New Market Formations in its type area.

The type section of the St. Paul Group is 9 miles west of Hagerstown, Maryland (Neuman, 1951, p. 278). Here the Row Park Formation consists of vaughanite as it does through most of the west side of the Great Valley. On the east side of the Great Valley, however, it consists of granular limestone. The term New Market was first used by Cooper and Cooper (1946, p. 72) for a series of dove-colored micrites called vaughanites. The term vaughanite has considerable local significance for geologists working in the Great Valley because of the economic importance of these beds, i.e. their remarkable purity. As defined in the Glossary of Geology and Related Sciences (1957, p. 312), the term vaughanite is used for ". . . fine-textured limestones which occur at various horizons throughout the Paleozoic and Mesozoic sections, which contain few fossils in their composition, and break with a more or less pronounced conchoidal fracture. Limestones of this type approach rather closely the uniformity and fineness of texture seen in lithographic limestones." In addition the vaughanites typically have a dove-color, waxy fractured surface, and translucent fracture edge. Although the dove color is medium light gray (N6), it frequently has a marked brownish cast that is quite distinctive. "Birdseye" structure is common and a blocky rather than rounded weathered fracture surface abounds in the purest beds. The term vaughanite is used only in an informal sense in this report.

The St. Paul occurs principally in a narrow belt between the Beekmantown Group on the east and the Martinsburg shale on the west. On the south, about half a mile east of Worleytown the belt is about 1,500 feet wide. North of Greencastle it splits into two belts, the easterly one

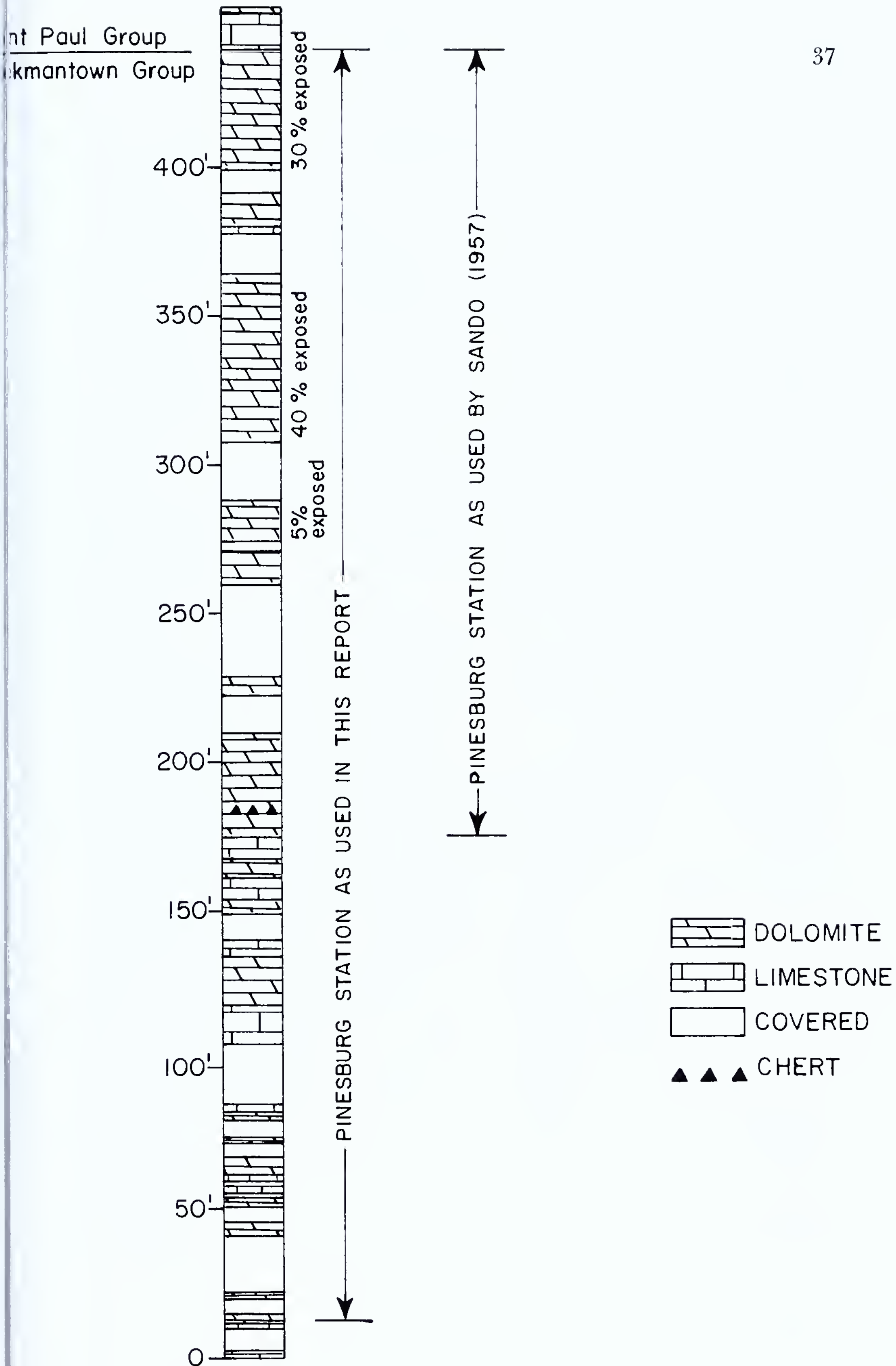


Figure 18. Usage of the name Pinesburg Station Formation and its relation to the St. Paul Group at Worleytown.

about 3,000 feet wide and the westerly one 1,500 feet wide. It underlies low, gently rolling terrain with some areas of good outcrop.

Two sections of the St. Paul Group were measured by Neuman (1951). The best exposed sections are near Kauffman (Neuman, 1951, p. 321 his section 30) and near Marion (Neuman, 1951, p. 322, his section 31). In both of these sections the Row Park and New Market Formations are recognized. The Row Park was further divided by Palacas (1957) at these localities into a lower Social Island Member and an upper Browns Mill Member.

An informal threefold division of these beds was made by Stose (1909, p. 7). He recognized the lower half composed of massive and thin-bedded limestone; a middle quarter of massive pure limestone with *Maclurea* and black chert, light colored in the lower part and dark blue in the upper part; and an upper quarter composed of thin-bedded, fine-grained vaughanites. This is not unlike the subdivision of Neuman (1951) as the break in the middle of the central unit can be selected as the Row Park—New Market contact.

For mapping purposes the St. Paul Group cannot be readily divided into its component formations or the proposed members. Although the St. Paul has unique lithologies that are readily distinguished from the other carbonate formations, in limited outcrop there is no single St. Paul lithology so restricted that it can indicate its stratigraphic position. Also major lithofacies changes, that are imperfectly understood, occur within the St. Paul. As Neuman (1951, p. 292) states, faunal criteria are conclusive in differentiating the two formations. For these reasons the St. Paul Group is not differentiated on the geologic map (Plate 1).

The best and most complete exposures of the St. Paul Group (Neuman, 1951, p. 322, his section 31) are 7,000 feet west and slightly north of where the Pennsylvania Railroad passes through the town of Marion. The exposures (Appendix, locality 4) occur on the north side of a small tributary that flows into Conococheague Creek. Other good exposures are 1.6 miles N70°W of Kauffman along the Pennsylvania Railroad (Neuman, 1951, his section 30) and 0.8 miles east of Worleytown (Neuman, 1951, his section 29).

Figure 19 is a generalized diagram showing distribution of various major limestone lithotypes in the St. Paul Group based on sections measured by Neuman (1951). From this diagram it is apparent that although the vertical succession throughout the area is approximately the same, some major beds are only of local extent and others change markedly in thickness in a short distance. The major units shown as extending across the area change their lithologic character significantly so that the correlations of these units is in part this writer's interpretation. Again it should be emphasized that there are significant lithologic

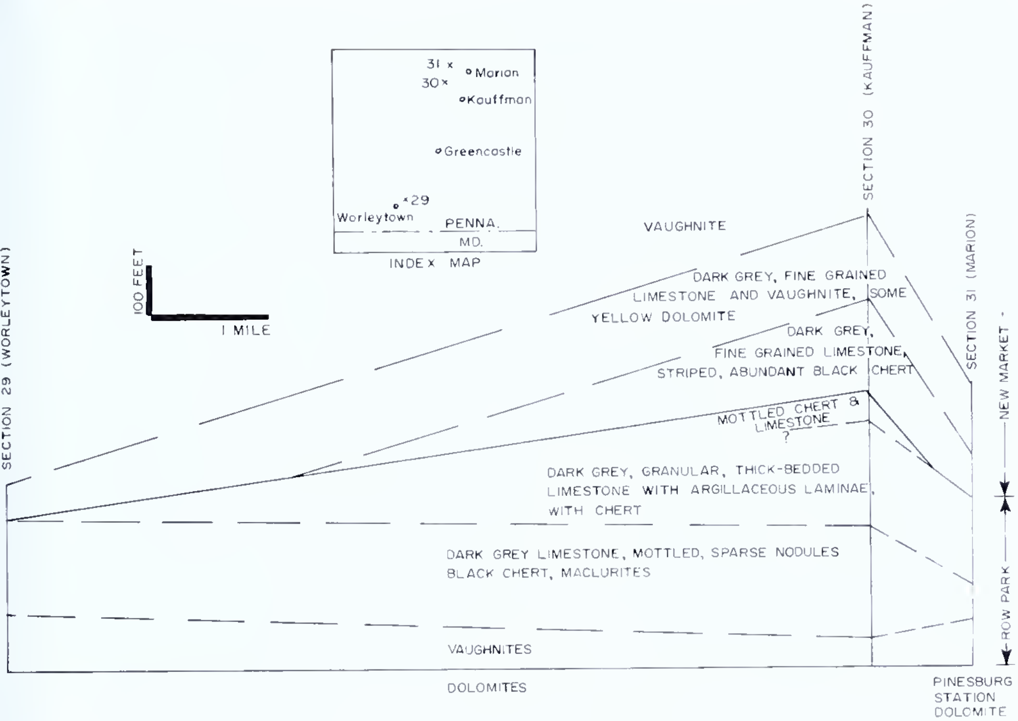

31 ×
30 ×
Marion
Kauffman
Greencastle
×29
Worleytown
PENNA.
MD.
INDEX MAP
100 FEET
1 MILE
SECTION 29 (WORLEYTOWN)
SECTION 30 (KAUFFMAN)
SECTION 31 (MARION)
VAUGHNITE
DARK GREY, FINE GRAINED LIMESTONE AND VAUGHNITE, SOME YELLOW DOLOMITE
DARK GREY, FINE GRAINED LIMESTONE, STRIPED, ABUNDANT BLACK CHERT
MOTTLED CHERT & LIMESTONE
?
DARK GREY, GRANULAR, THICK-BEDDED LIMESTONE WITH ARGILLACEOUS LAMINAE, WITH CHERT
DARK GREY LIMESTONE, MOTTLED, SPARSE NODULES BLACK CHERT, MACLURITES
VAUGHNITES
DOLOMITES
NEW MARKET
ROW PARK
PINESBURG STATION DOLOMITE

Figure 19. Generalized lithologic variations with the St. Paul Group. Data from Neuman (1951).

changes in the St. Paul such that in areas of limited outcrop or structural complexity although one can readily recognize the group, the formations cannot be discriminated.

Similar arguments can be made against the subdivisions of the Row Park Formation in the members suggested by Palacas (1957). Figure 20 is based on Plate 6 of Palacas (1957). His sections 1, 2, and 3 correspond to Neuman's sections 31, 30, and 29 respectively. The discrepancy in thickness of the Row Park in his section 2, which is 736 feet and is the same section measured by Neuman (1951, his section 30) which is 545 feet, is that Palacas apparently included a considerable amount of Neuman's basal New Market beds in the Browns Mill Member and some dolomites from the Pinesburg Station in the Social Island Member. There are considerable discrepancies in the other sections measured by Palacas. This ambiguity arises in the definition of these members with reference to extant formations; it is best not to utilize the member subdivisions but recognize that they do, in a general way, indicate lithologic variation in the Row Park Formation.

From the present work as well as the works of others, it is possible to distinguish several basic units in the St. Paul Group, that are particularly applicable in the area near Marion and Kauffman (MacLachlan and Root, 1966, fig. 10).

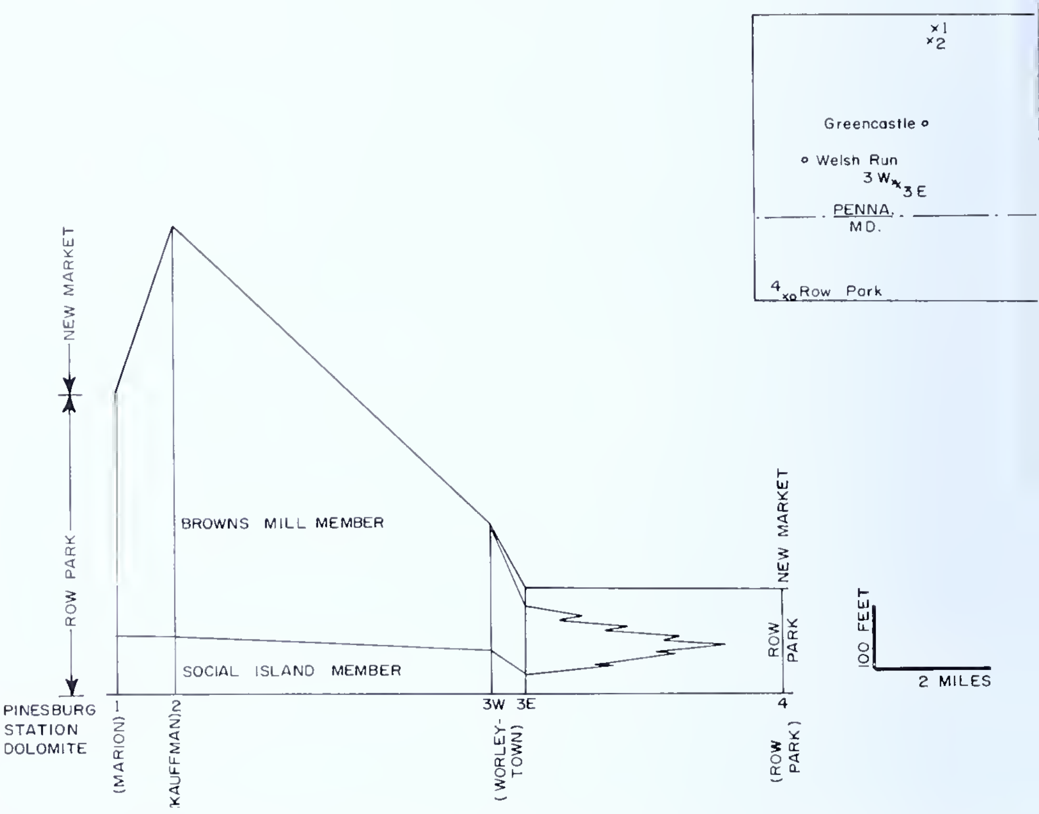


Figure 20. Members within the Raw Park Formation of the St. Paul Group after Palacas (1957).

The beds composing the upper Beekmantown, and referred to as Pinesburg Station, consist of interbedded dolomites and limestones some of which are vaughanites. These grade upward into beds of pure vaughanite at the base of the St. Paul, which is arbitrarily selected above the highest dolomite. The vaughanites are from 50 to 120 feet thick. Figure 21 illustrates vaughanites with birdseye structure that results from clear sparry calcite infilling of fossil and other undetermined voids.

Above this is a dark gray, thick-bedded limestone composed of fine-grained skeletal and detrital material, with irregular argillaceous laminae. Locally this zone contains spectacular shells of *Maclurites magnus, Girvanella* and black chert nodules. Figure 22 shows the clastic nature of this unit. Thickness of this unit ranges from 70 to 220 feet and it is the most readily traceable unit in the group.

This is overlain by a zone of dark gray, granular, thick-bedded limestone with argillaceous laminae and some chert. Thickness ranges from 205 to 170 feet. This zone is apparently absent to the south at Worleytown (Figure 19). At Kauffman another 75 feet of dark gray, mottled, somewhat cherty limestone is present above these beds. The Row Park which is composed of the units described in the preceding paragraphs ranges from about 300 feet to 550 feet in thickness.

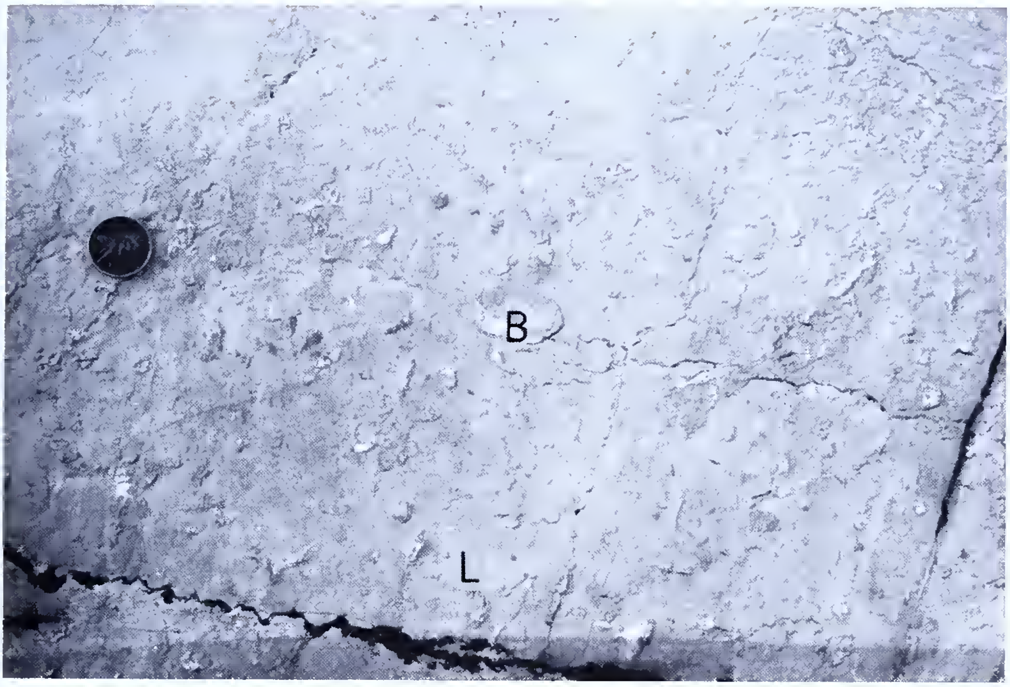


Figure 21. Micritic limestone (L) with 'birds eye' (clear calcite spar) structure (B) in the lower part of the St. Paul Group. This is also referred to as a vaughanitic limestone or vaughanite.

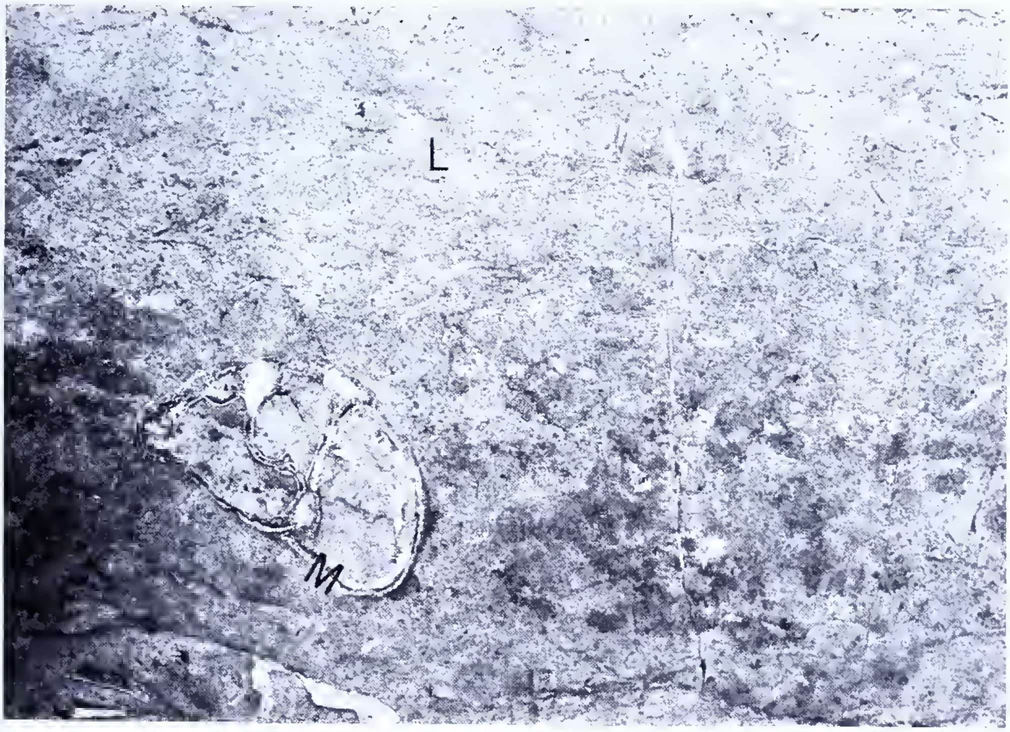


Figure 22. Fine-grained mechanical limestone (L) showing a cross section through a 2-inch specimen of *Maclurites (M)*. Lower part of the St. Paul Group.

The base of the New Market can be selected readily at Kauffman and Marion because of the abundant black chert nodules which are present in the thin-bedded, dark-gray, fine-grained, striped to banded limestones. This unit which attains a maximum thickness of 180 feet at Kauffman is only 80 feet thick at Marion and absent at Worleytown. Figure 23 shows the character of this rock type.

Overlying the cherty horizon is a sequence of fine-grained, dark-gray limestone and minor bluish vaughanites. Some dolomitic limestone and yellowish weathering dolomite are present at Worleytown and Kauffman respectively. At Marion the nine dolomitic beds present are part of a cyclical limestone-dolomite alternation. The cycle (Figure 24) is initiated by algal stromatolites that are space laterally linked hemispheroids with some close linked hemispheroids as a microstructure in the constituent laminae (Logan, and others, 1964, p. 74). These obvious algal-stromatolite beds pass laterally and vertically in structureless blue-gray limestone micrites that may also be of algal origin. Wolf (1965) discussses the process of "grain diminution" of algal colonies to structureless micrite. This effect may be of importance here and in the origin of the pure micrites of the Zullinger Formation and micrite-chert zone at the base of the Rockdale Run Formation all of which have important algal-stromatolite constituents. The upper surfaces of these beds show mud cracks, the spaces of which are infilled by yellow-gray dolomite detritus (?). Above these are beds of medium-yellow gray, finely laminated, dolomite (Figure 25), the upper surface of which is sharp and overlain by another cycle of algal stromatolites. The limestone beds are 3 to 4 feet thick and the dolomite beds 1 to 2 feet thick. Two such cycles are well exposed at Marion and appear to represent normal shallow marine limestone deposition alternating with desiccation and deposition of supratidal (?) dolomite. As many as nine cycles may be present in this interval. The sections at Kauffman and Worleytown contain several dolomite beds at approximately the same horizon but in a simple alternation of beds rather than cyclically bedded.

The uppermost part of the St. Paul consists of a series of vaughanites. At the very top these are interbedded, through an interval of perhaps 20 feet, with the cobbly limestones somewhat similar to the cobbly limestone of the Chambersburg Formation. For purposes of completeness, a measured section of the St. Paul near Marion is included in the appendix (Locality 4).

The thickness of the St. Paul Group is about 1,000 feet at Marion but there is some structural complication in the upper third of the group so that this is an approximate value. At Kauffman the writer calculated 980 feet whereas Neuman (1951, p. 321) calculated 1,005 feet of St. Paul. The thickness of the Row Park Formation varies from 330 feet at Marion,

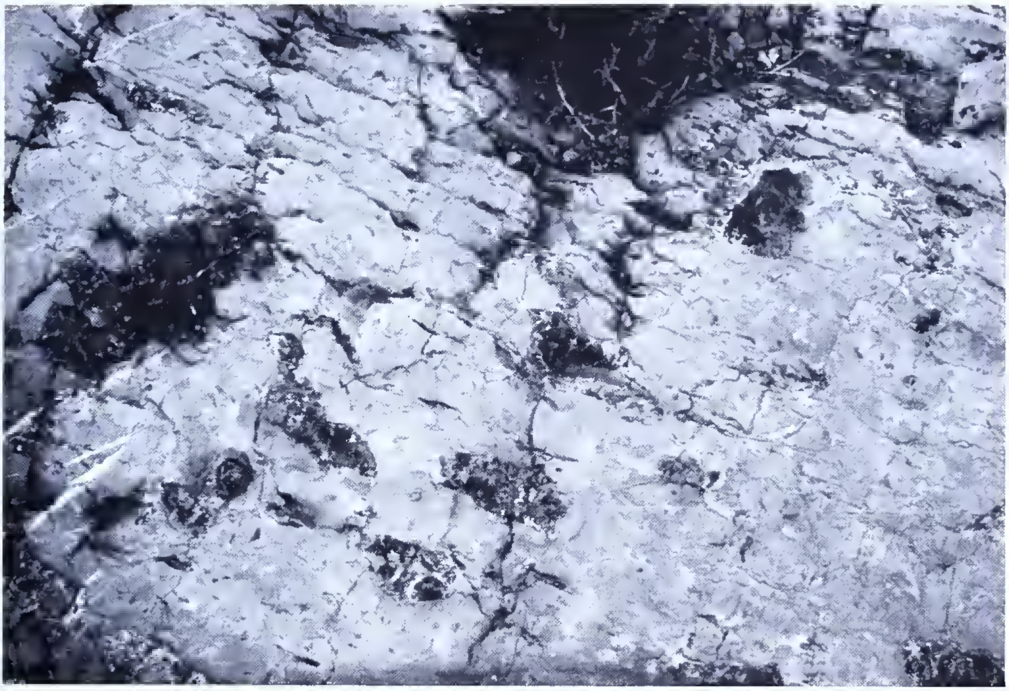


Figure 23. Thin-bedded medium groy limestones and black chert nodules in one central part of the St. Paul Group. The nodules are several inches across.

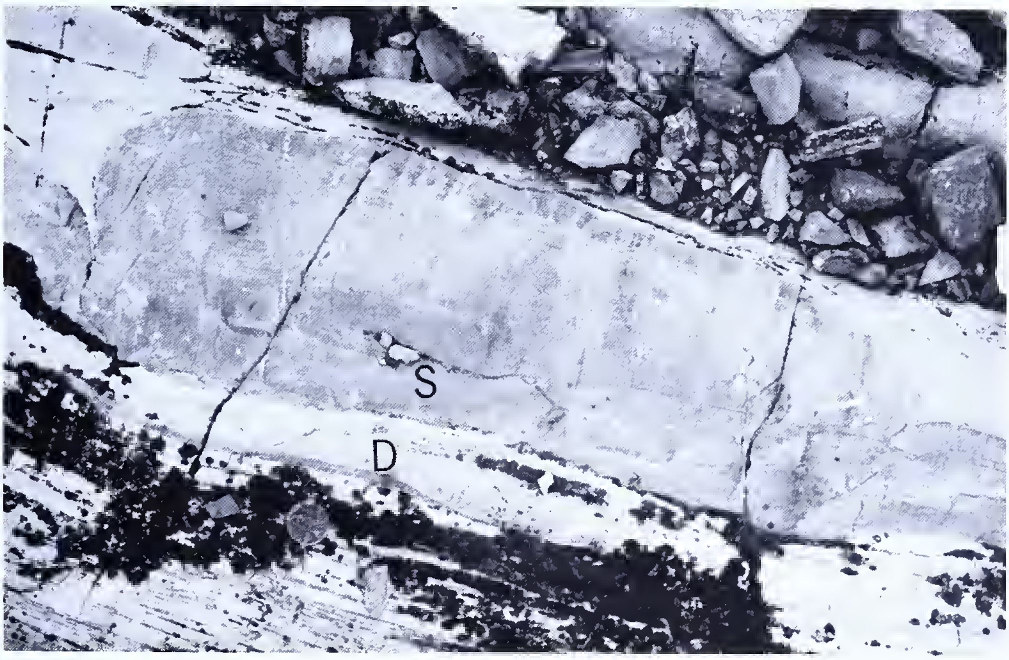


Figure 24. Limestone stromatolites (S) averlying a laminoted dolomite (D) developed in one cyclical sequence of the St. Paul Group. (Appendix, measured section 4.)

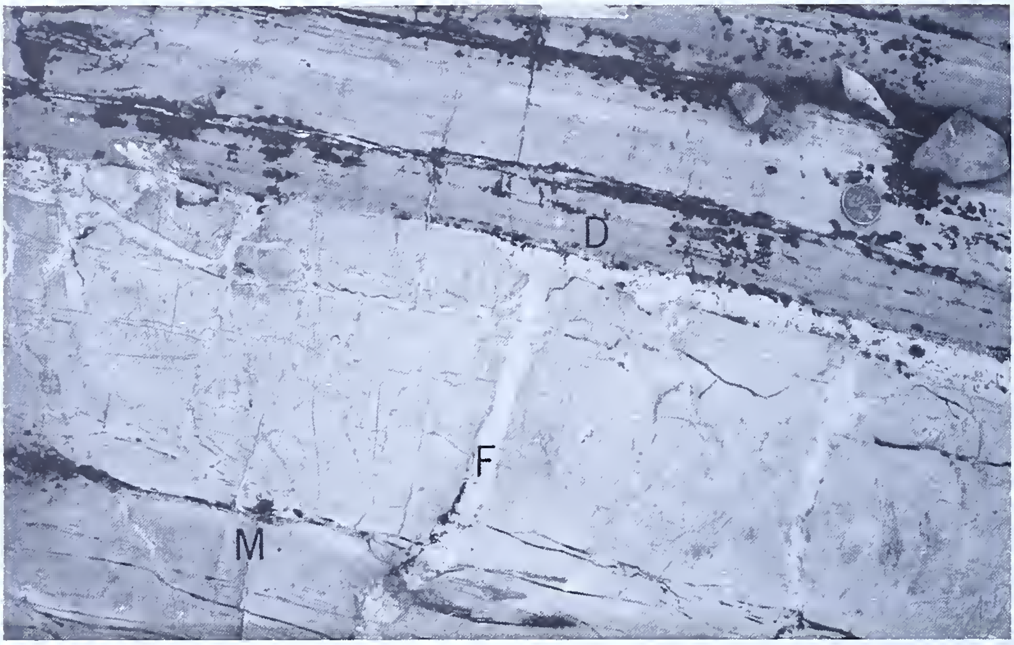


Figure 25. Mud-cracked limestone (M) representing termination of a cycle overlain by laminated dolomites (D). Note the well-developed mudcrack fissures (F). Part of the same cycle as Figure 24.

to 460 feet at Kauffman, 295 feet at Worleytown, and 190 feet at Sylvan Grove, Maryland (Neuman, 1951). At Martinsburg, West Virginia, the Row Park Formation is absent and the St. Paul Group is represented by 150 feet of the New Market limestone (Page and others, 1964). From Martinsburg, for over 120 miles south along the Great Valley, past Staunton, Virginia, thin New Market vaughanites rest disconformably upon the Beekmantown. Across the Great Valley from the mapped area the St. Paul Group has thinned to 160 feet at Dickey (Pierce, 1966, p. 15).

No physical evidence of a disconformity at the base of, or within, the St. Paul Group is present in the mapped area. Although it might be easiest to explain the complexity of lithofacies changes in Figure 19 by a disconformity at the base of the New Market Formation none was observed. However, it should be mentioned that in view of the structural complexity and incomplete exposure, a divergence in primary bedding attitudes of a few degrees between the Row Park and New Market Formation might not be apparent.

The St. Paul Group is of lower Middle Ordovician age assigned to the Marmor and Ashby Stages by Cooper (1956).

Chambersburg Formation

The Chambersburg limestone was named by Stose (1906, p. 211) to designate 1,000 feet of cobbly limestone typically exposed near Chambersburg. Subsequent work mainly of a biostratigraphic nature has included the studies of Cooper and Cooper (1946), and Craig (1949).

Outcrop patterns of the Chambersburg Formation are in large part associated with the outcrop pattern of the St. Paul Group. The limestones occur as a narrow belt, at most 2,000 feet wide, between the Martinsburg shale on the west and the St. Paul-Beekmantown carbonates on the east. Faulting and folding of these rocks complicate the outcrop pattern. There is a narrow belt southeast of Worleytown, and another belt just west of Greencastle. Northwest of Greencastle it splits into two narrow belts, one enclosing an anticlinal fold and the other as part of a block repeating the anticlinal limb.

Because of its narrow width the Chambersburg does not have a typical topographic expression, but it does underlie a flat, low area. The limestone cobbles derived from the formation litter the ground and as such are distinctive. In addition, the outcropping bedrock does not protrude above the soil as ledges or knobs, but normally is at the same surface level as the adjacent regolith; it seems to 'peek' through the regolith. None of the other carbonate units outcrop in this subdued manner.

There is only one good exposure of the Chambersburg in the mapped area. This is the section in the spur of the Pennsylvania Railroad cut located 8,000 feet N60°W of Kauffman where the main line of the Pennsylvania Railroad passes through that town. This section has been measured by several workers and a detailed description is presented by Cooper and Cooper (1946, p. 59).

From their description it is apparent that the general lithologic aspect of the Chambersburg is that of a sequence of cobbly limestone. This impression is even more striking in natural exposures protruding through the regolith as most of the more massive appearing units in the railroad cuts tend to become cobbly upon prolonged weathering. The cobbly habit of the limestone is the result of wavy laminations or shaly partings that cross the bedding at high angles. Upon weathering they form rounded lenticular pieces resembling rough cobblestones or squarish nodules. Figure 26 is typical of the Chambersburg lithology. The writer has not been able to subdivide the Chambersburg into mappable units because of similarity of lithology throughout the sequence and generally poor outcrop.

A subdivision of the Chambersburg was made by Craig (1949) on the basis of a study in south-central Pennsylvania. He suppressed the term Chambersburg, dividing these beds into a lower Shippensburg Formation composed of the Pinesburg and Fannettsburg Members and an upper Mercersburg Formation consisting of the Housum and Kauffman Members. He also recognized the Oranda Formation of Cooper and Cooper (1946) above these beds and below the Martinsburg Formation. Unfortunately, these are not objective rock-stratigraphic units as faunal content is diagnostic in the recognition of his subdivisions. Again, in natural weathered exposure it is almost impossible to distinguish any significant

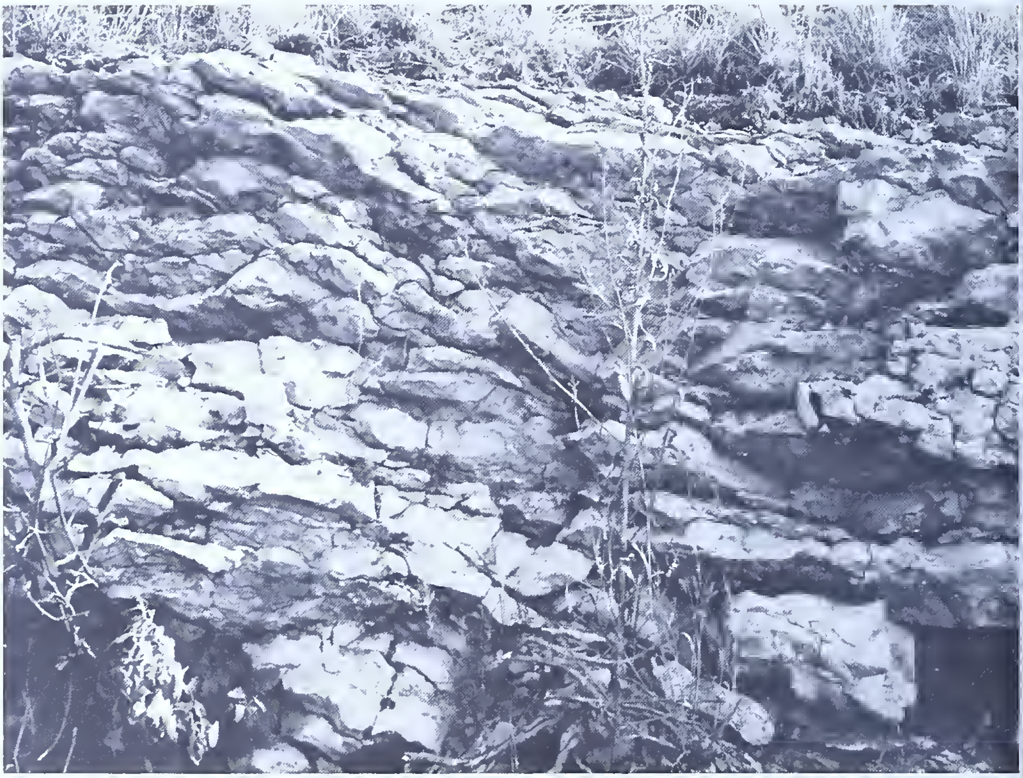


Figure 26. Cobbly limestones typical of the Chambersburg Formation.

lithologic difference within the Chambersburg cobbly limestones. Craig's 1949 study is important because he recognized ten metabentonite beds in the section at Kauffman. The metabentonites range in thickness from 1 to 8 inches in thickness, with a medium thickness of about 2 inches. He (Craig, 1949, p. 717) recognized a regional unconformity at the base and top of the Shippensburg Formation. This has not been noted by previous workers or in the course of this study. There is a slight problem in picking the St. Paul-Chambersburg contact as the vaughanites and cobbly limestones, are interbedded over an interval of at least 20 feet. The top of the St. Paul was arbitrarily selected at the last occurrence of vaughanites. The regional unconformity present at the top of the Shippensburg was not observed. It is hoped that continued mapping to the north will yield additional information concerning the stratigraphic complexities in the Chambersburg Formation.

The 60-foot thick cobbly limestone unit 10 of Cooper and Cooper (1946) has been assigned to the Oranda Formation by Craig (1949, p. 739). As the recognition of the Oranda Formation is questioned, these beds have been included with the Chambersburg Formation by the writer, primarily because the unit is exposed in so few places as to be unmappable even though it may be lithologically distinct from the underlying beds of the Chambersburg. Beds referable to the Oranda as defined by Craig (1949, p. 739) are not lithologically similar nor temporally equivalent to the Oranda beds at their type section in Virginia.

Only in two places is the Chambersburg-Martinsburg contact exposed, and there is a problem in reconciling the differing lithologic relations at the two localities. The Chambersburg-Martinsburg contact is exposed in a road bank 8,200 feet N6°W of where the Pennsylvania Railroad passes over the main road at Kauffman. About 50 feet of Chambersburg limestone is poorly exposed, the lower part of which is fossiliferous, cobbly, dark-gray limestone. The upper part is flaggy, coarse skeletal detritus composed mostly of disarticulated crinoid columnals with subordinate trilobites and tiny gastropods. Pyritization of fossil fragments and preservation of chitinous (?) material is common. These are probably the *Reuschella "edsoni"* beds of Cooper and Cooper (1946, p. 59). Above this is a 5-foot thick zone of interbedded dark, argillaceous, flaggy limestone and calcareous shale in beds 1 to 2 feet thick. This is overlain by about 60 feet of banded to laminated calcareous black shale with minor interbeds of homogeneous black shale, all referable to the Martinsburg Formation. Outcrop ends here but rock float indicates normal Martinsburg shale above these transition beds.

The other exposure is along U. S. Highway 11, 2,500 feet north of the intersection of U. S. 11 and State Highway 16. The Chambersburg is well exposed in the railroad cuts just to the east of the highway at the overpass, and consists of perhaps 30 feet of thick-bedded, medium gray, cobbly, limestone. Along the highway it can be seen that the limestone is overlain sharply by about 30 feet of very fine-grained, hard, medium to light gray, thin-bedded sandstone considered to be part of the Martinsburg. The lower few feet of sandstone are calcareous and structureless but above this the sandstone shows wispy to well-developed laminations with mottled and burrow structures. Above this is float of more normal Martinsburg shale lithology.

Apparent thinning of the underlying Chambersburg Formation at the second locality suggests a local unconformity below the sandy zone. Such local unconformity is probably the major factor in explaining the different sequences in the two relatively close locations. However, exposures are inadequate to evaluate the contribution of lateral facies variation which may also be considerable.

The thickness of the Chambersburg in the railroad cut at Kauffman was measured by the writer as 765 feet which compares favorably with the thickness of 749 as determined by Cooper and Cooper (1946) at the same locality. Assuming that there is no faulting in this section, a thickness of 750 feet of Chambersburg strata is a reasonable value in this area.

The age of the Chambersburg, based on excellent faunal evidence, is of Middle Ordovician age and has been firmly correlated to the classic Black River and lower Trenton Groups in New York State.

Martinsburg Formation

Martinsburg Formation was the term applied by Keith (1894) to the shale hills near Martinsburg, West Virginia. As these shales can be traced north into Pennsylvania, Stose (1909, p. 10) applied the term in Franklin County, and later workers extended the term as far north as the Delaware River. The Martinsburg is the least understood geologic unit in Franklin County. Such basic facts as thickness and stratigraphic sequence are still unknown because of the paucity of outcrop and structural complexity.

The Martinsburg is restricted to the western portion of the mapped area. It forms a belt about 3.5 miles wide between Cambro-Ordovician limestones on the east and west sides of the Great Valley. It is also present in a small area just west of Greencastle where it occurs on the nose of a plunging anticline and in a small belt west of Kauffman where it is found in the west flank of the faulted anticline.

Characteristically the Martinsburg forms a low plateau declining from elevations of about 640 feet in the north to 580 feet in the south. This surface has been termed the Harrisburg peneplane by Stose (1909, p. 10). The shale plateau which is about 50 feet higher than the adjacent limestone terrain is highly dissected by small streams which flow in steep, rugged, and narrow valleys. The Conococheague Creek is the only stream that has cut down sufficiently to form a narrow flood plain. The morphologic expression between the limestone and shale terrains as shown on the topographic base (Plate I) is striking.

Because of the limited exposure and structural complexity, it is difficult to determine a Martinsburg lithologic sequence in the area. Stose (1909, p. 10) states that the lower part of the formation is black, carbonaceous and fissile becoming calcareous near the base and grading into the Chambersburg Formation. In the middle of the formation the shale is dark and slightly calcareous, and the upper portion is composed of a soft sandstone of yellow-green color but west of Chambersburg it is exceptionally hard, coarse grained, and thick bedded. Based on a regional study McBride (1962, p. 42) concluded that the Martinsburg is composed of a lower shale member which passes upward into a member of interbedded graywacke and shale (flysch). The division of the Martinsburg into lower shaly and upper arenaceous parts is accepted in this report although this relation remains to be conclusively demonstrated in the Cumberland Valley. The distribution of the sandy upper portion as mapped by Stose (1909) is shown in Figure 27.

The lower shaly part of the Martinsburg is not exposed to advantage except along the cuts of the Pennsylvania Railroad between Williamson and Stone Bridge. However, the structural complexities have not been resolved in this series of exposures. Usually the shales weather yellowish-

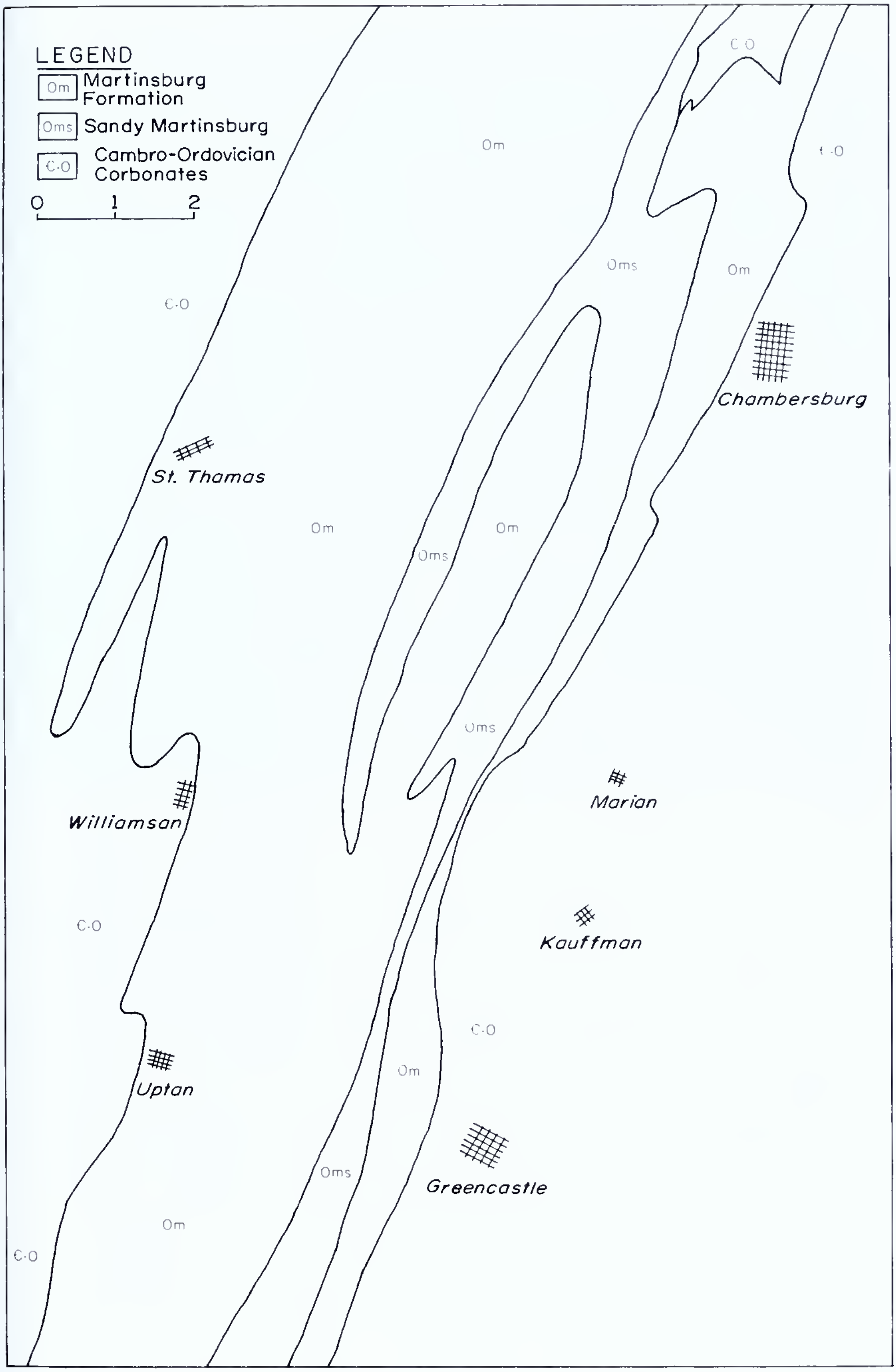


Figure 27. Distribution of the sandy facies within the Martinsburg Formation area of outcrop. Adapted from Stose (1909).

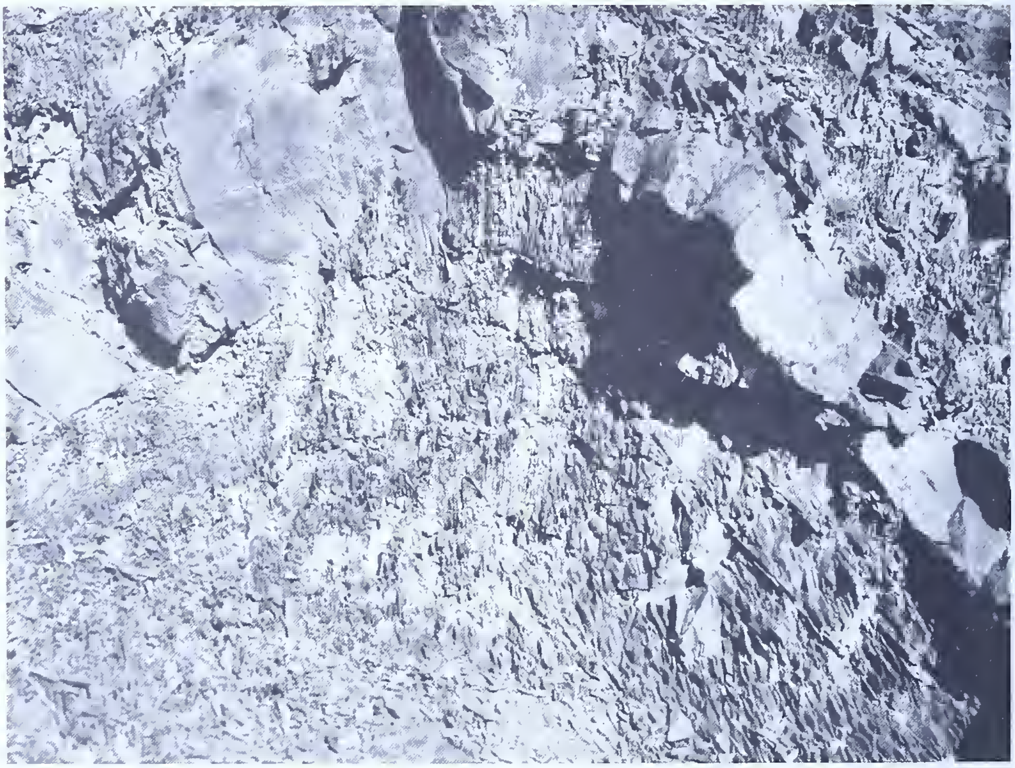


Figure 28. Flexure-slip anticline developed in the Martinsburg Formation, and expressed by a graywacke bed. Note development of vertical fracture cleavage in the shale above and below the graywacke bed.

brown (10YR 6/4) and because they break into small pieces as a result of a pervasive fracture cleavage (Figure 28), they usually exhibit the same coloration on an interior surface. However, the original dark to medium gray color can be seen in some fresh cuts.

Exposures in the upper sandy portion of the Martinsburg are better than in the shales. There are some good exposures close to the contact with the carbonates especially on the west side of Conococheague Creek at Social Island slightly north of the mapped area. Sandstones predominate over the shales. The sandstones are fine to very fine grained, dark gray to dark buff graywackes and in beds up to 6 feet in thickness although they average considerably less (Figure 29). The sandstones are poorly graded throughout much of the section; the grading frequently shown by subtle features such as color contrast and surface texture rather than obvious grain size variation. The base of the beds are frequently irregular, indicating groove casts. In some instances granules and fine pebbles have accumulated in the lowest part of a groove cast and are an excellent indicator of superposition of strata. Most of the

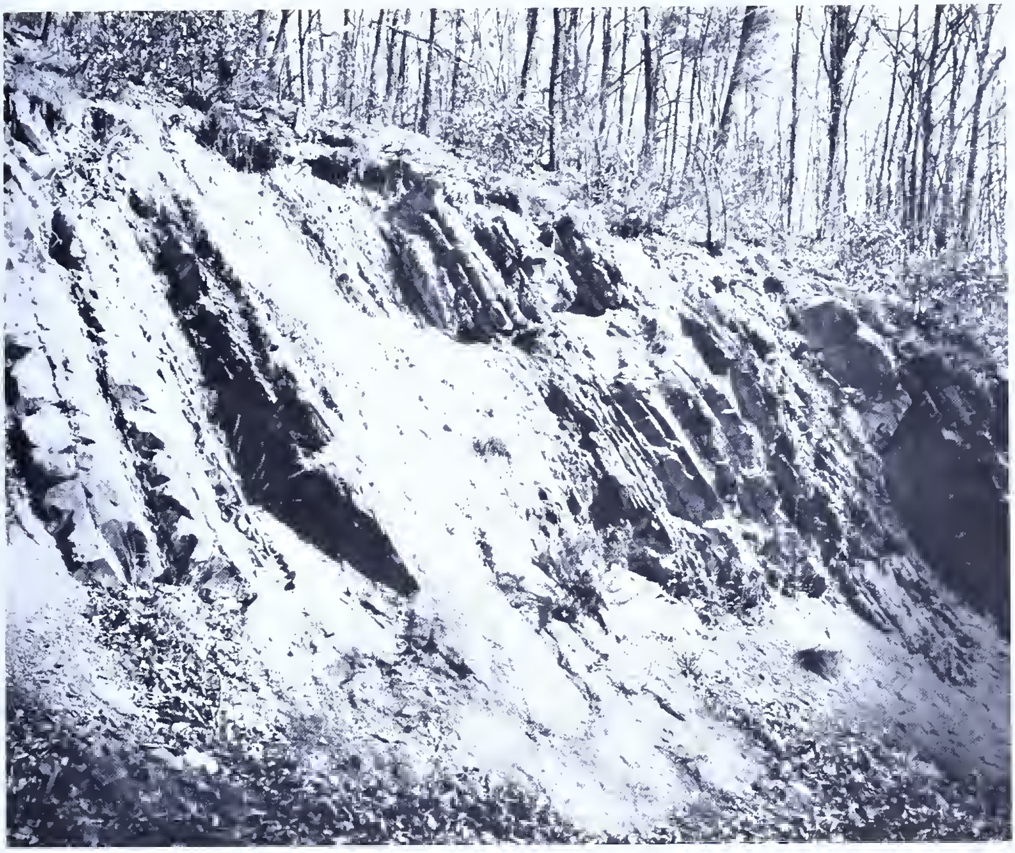


Figure 29. Massive jointed graywacke beds interbedded with subordinate amount of shale typical of the sandy portion of the Martinsburg Formation.

sandstone grains are fine to very fine grained and there is no internal structure such as lamination and cross stratification.

It should be noted here that if the distribution of the sandy portion of the Martinsburg (Oms) as shown on Figure 27 is substantially correct and it is in the upper part of the Martinsburg, then certain problems arise. First, what is the structure where Martinsburg (Oms) limbs enclose a belt of presumably younger Martinsburg (Oms)? Secondly, why is the Martinsburg (Oms) so close to the limestones on the east side of the valley and so distant on the west side?

The thickness of the Martinsburg has not been resolved in the Cumberland Valley. Stose (1909, p. 10) calculates the thickness of the Martinsburg at 2,000 feet with the shales constituting 800 feet and the sandstones 1,200 feet but this figure is subject to question. Along the Great Valley from Virginia to New Jersey thickness estimates range from 2,250 to 11,000 feet (McBride, 1962, p. 43). Much work remains to be done here before the Martinsburg Formation can be discussed in terms of lithologic succession, stratigraphic framework, and geologic history.

DEPOSITIONAL HISTORY

The depositional history of the Cambrian and Ordovician sediments from the Tomstown Formation to the Martinsburg are set forth briefly in this section. The restricted area of this report and limited exposures permit only the general interpretation that miogeosynclinal sedimentation occurred principally in a stable, shallow, open-marine sea until the Middle Ordovician when conditions were less stable and seas became deeper.

The carbonate beds of the Zullinger-St. Paul sequence were deposited in an environment probably somewhat similar to that of the present Bahama Banks platform. The seas were so shallow that slight movements of sea level could shift environments from shallow open marine (mechanical, oolitic, and intraformational conglomeratic sediments) to intertidal (stromatolitic and vaughanitic sediments) or supratidal (penecontemporaneous dolomites).

Environmental conditions changed during the deposition of the Chambersburg Formation. The argillaceous composition and cobbly character of the limestones indicate conditions of deeper marine water than existed during the deposition of the older sediments and development of a paleoslope (Wobber, 1967). Bentonite beds and probable unconformities within the formation are an indication of the beginning tectonic instability of the region. As the basin deepened and regional tectonism became more pronounced, the flysch sediments of the Martinsburg Formation were deposited.

SURFICIAL DEPOSITS

The surficial deposits for purposes of this report are shown simply on the geologic map (Plate 1) as colluvium-terrace gravels and alluvium. This classification does not do justice to the variety of surficial deposits that can be distinguished. On the west side of the valley, Pierce (1966) distinguished screes, block fields, and shale-chip rubble on interfluves; rubble ridges, debris slides and avalanches, rubble fans and rubble valley fills, modern alluvium and roundstone diamicton on valley bottoms.

The term colluvium as used here includes loose and unconsolidated deposits such as talus and cliff debris usually at the foot of a slope or cliff and brought there chiefly by gravity. The terrace gravels of Stose (1909, p. 12) represent stream deposits. However the two types occur in approximately the same areas and are not differentiated. In places, these deposits are as much as 130 feet thick.

The term alluvium is used here to include all detrital accumulations deposited by modern rivers. Thus it includes all the recent stream flood plains in the area. Older terrace gravels adjacent to mountains are not differentiated from the colluvium. The disposition of alluvium and colluvium terrace gravels is shown on the geologic map (Plate 1). Transported regoliths on the interfluves and limestone residuum and soil were not studied in this report.

It is appropriate to mention here the unique occurrence of lignite at Pond Bank and its implications. The deposit, which is located about 2,300 feet north and slightly east of the town of Pond Bank, has been dated by Tschudy (1965) on the basis of spores and pollen as of Late Cretaceous age. This deposit according to Pierce (1965) accumulated in a local sink developed on the carbonates. The lignite is a seam about 20 feet thick occurring 40 feet below surface and resting on more than 170 feet of carbonate residuum. Apparently this deposit has been lowered hundreds of feet by solution of the underlying Tomstown carbonates. The lignite was encountered in a shaft used to mine iron ore about 100 years ago, and it was not surprising, therefore, that there have been no other lignite occurrences reported in the Cumberland Valley.

STRUCTURE

INTRODUCTION

Problems inherent in resolving the structural geology of the Great Valley are typical of those in many old mountain belts—1) lack of exposure, and 2) absence of topographic relief or drilled wells, thus eliminating the third dimension so vital in understanding the spatial configuration of the structures. Because of these problems it should be emphasized that the data and concepts presented in this section are an approximation of a very complex situation.

Only sparse detailed work has been done previously on total structural aspects of the Cumberland Valley in Franklin County. Stose (1909, also 1953) has reported on the structural geology of portions of Franklin and Cumberland Counties. Cloos (1947) in a classic paper studied oolite deformation as related to South Mountain structure and later (1951) mapped the geology of Washington County, Maryland which adjoins Franklin County on the south. The writer (Root, 1965, also MacLachlan and Root, 1966) discussed the structural geology of the Cumberland Valley. Farther south Sando (1957) and Page and others (1964) have contributed much of the knowledge of various portions of the Cumberland Valley. To the north Fauth (1968) and Freedman (1967) have mapped the geology of portions of South Mountain, and still further north MacLachlan (1967) has studied in detail the structural relations of the Cambro-Ordovician carbonates of Dauphin County.

Essentially the Cumberland Valley carbonates are part of the autochthonous South Mountain anticlinorium (Figure 30). Rocks from the Catoctin greenstones through the Middle Ordovician carbonates are involved in related folding and faulting. The flow cleavage (S_1) and fold pattern geometry are reflected through the entire sequence of rocks indicating that they have a common deformational history.

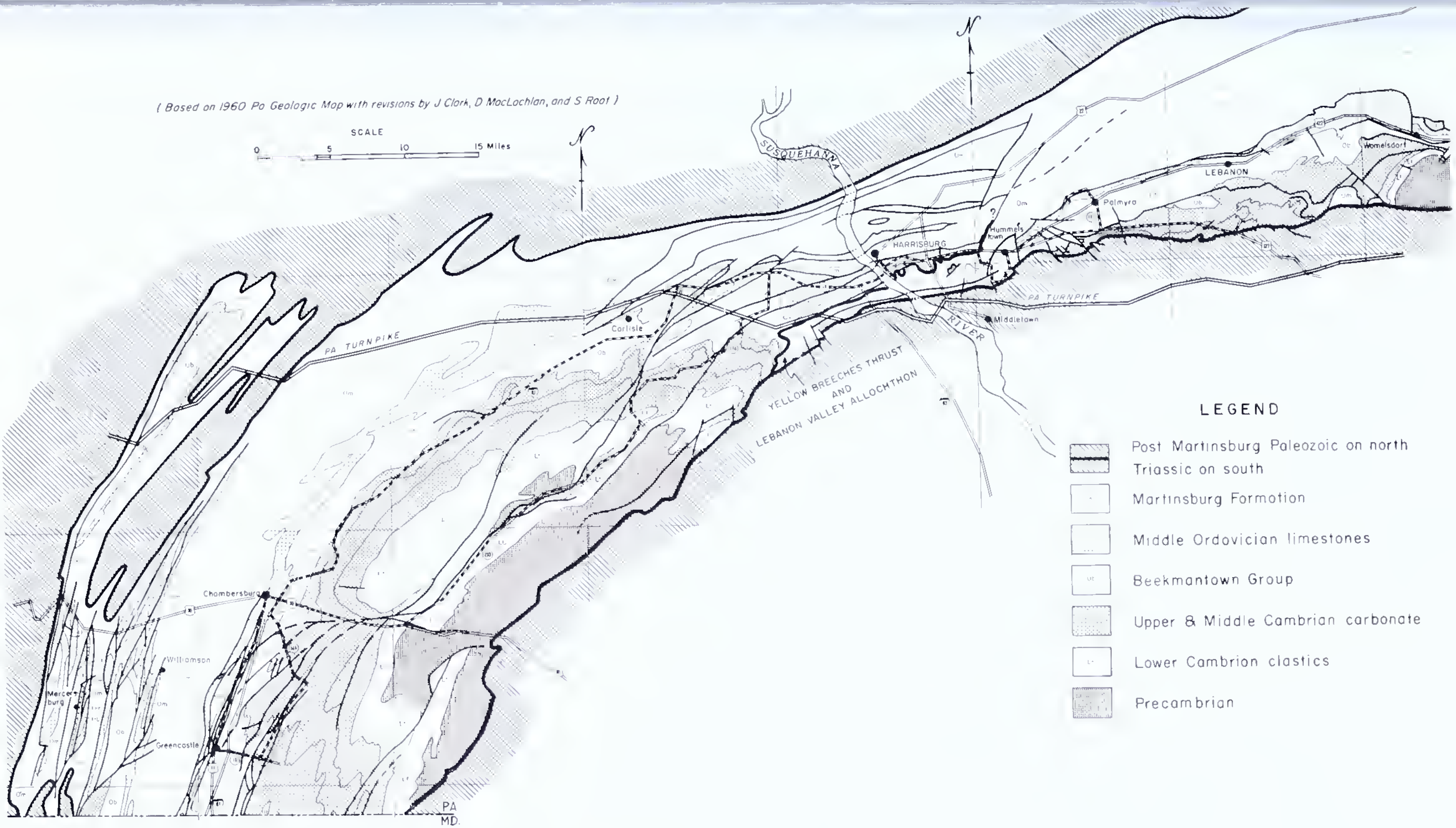
All major faults are rectilinear high angle reverse faults. Individual folds and faults can be traced more than 30 miles, and further extension is limited only by lack of detailed mapping. Although the structural geology is complex it is extremely regular and maintains this regularity probably to Elkton, Virginia, south of which the Blue Ridge may be involved in considerable thrusting.

GENERAL STRUCTURAL GEOLOGY

South Mountain at the north end of the Blue Ridge physiographic province is composed of a core of Precambrian Catoctin greenstones, rimmed by quartzite ridges of the Weverton, Harpers, and Antietam Formations. The Great Valley is floored by the Cambrian and Ordovician carbonates and by shales of the Martinsburg Formation. For purposes of structural consideration the writer follows the usage of Cloos (1951, p. 124) and divides the area into two major structural elements, the South Mountain anticlinorium on the east and Massanutten synclinorium on the west (Figure 30), separated in this area by the Carbaugh-Marsh Creek fault (Figures 30 and 31). This boundary lies within the valley and thus does not correspond to the physiographic division but it seems to mark a discontinuity in the character of deformation. An added measure of complexity is the varying response of these different rock types to a stress that apparently diminished from east to west.

Briefly the South Mountain anticlinorium includes rocks of the Catoctin greenstone, Chilhowee Group, and Cambrian and Ordovician carbonates that are folded into a doubly plunging anticlinorium dominated by an east dipping flow cleavage (Cloos, 1947); whereas the Massanutten synclinorium includes shales of the Martinsburg Formation with some upfaulted belts of Ordovician limestone folded into a northeast plunging synclinorium in which flow cleavage is absent.

The northern limit of the South Mountain anticlinorium is essentially south of Carlisle. Here quartzites of the Weverton, Harpers, and Antietam rim a narrow anticline which plunges to the northeast. The overlying Cambrian and Ordovician carbonates flanking the quartzites are cut off down plunge (Figure 30) by the Yellow Breeches fault (MacLachlan and Root, 1966). The Triassic border fault, which forms the eastern limit of the anticlinorium, changes direction so that it transects more of the anticlinorium near Carlisle but less to the south. Tracing the anticlinorium southward up plunge, the oldest rocks exposed are the Catoctin volcanics east of Shippensburg. A local structural culmination occurs here as the anticlinorium commences to reverse and plunge to the southwest and maintains this attitude into Maryland.



(Based on 1960 Pa Geologic Map with revisions by J Clark, D MacLachlan, and S Root)

Figure 30. Generalized geologic map of the Great Valley in Pennsylvania.

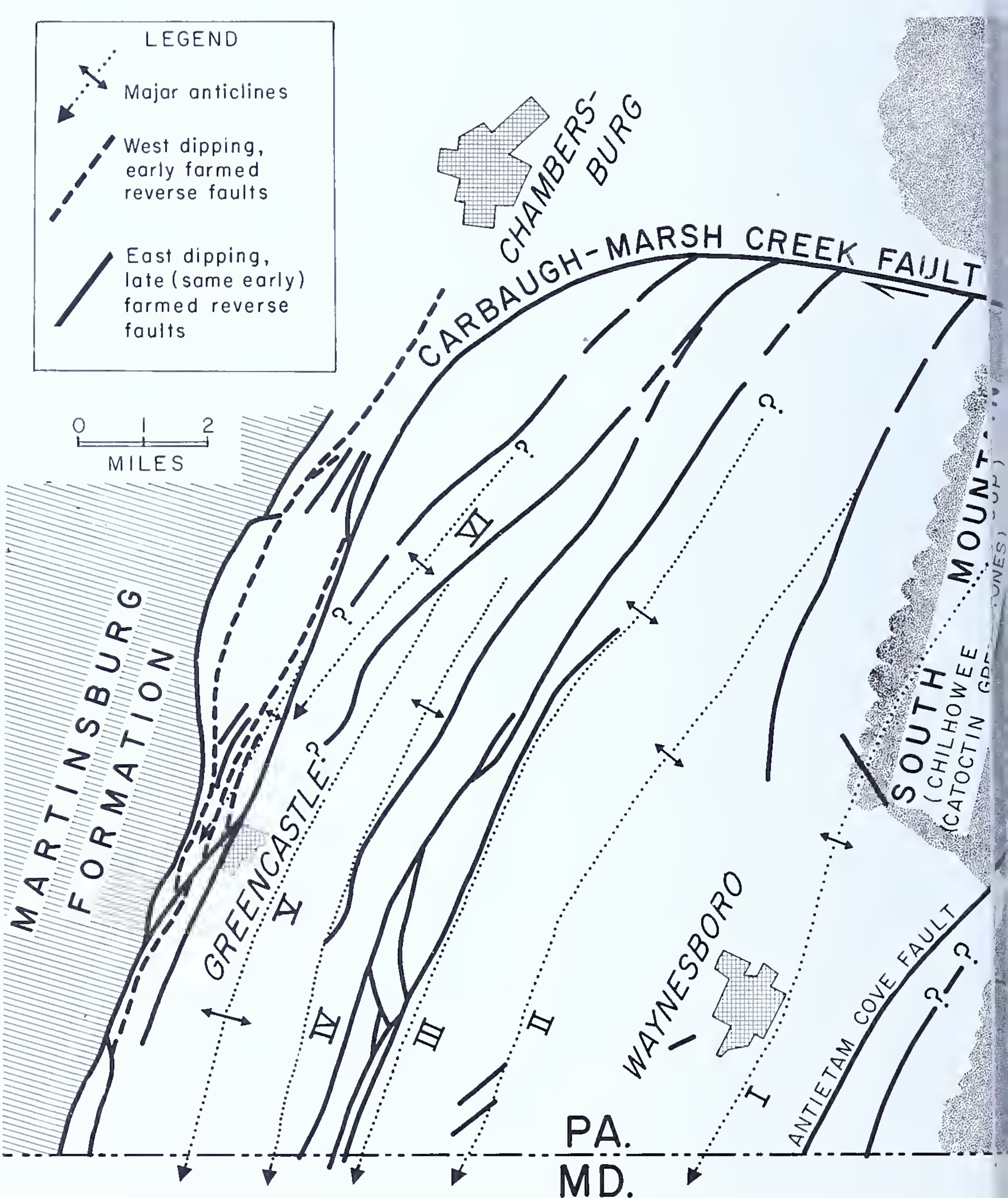


Figure 31. Tectonic sketch map of southeastern Franklin County.

The following description of geometry and mode of deformation of the South Mountain anticlinorium is from the excellent work of Cloos (1947, p. 845) based on analysis of oolite deformation in the Cumberland Valley of Pennsylvania and Maryland:

> The South Mountain fold is a large asymmetrical overturned anticline. Its axial plane dips to the southeast, and its crest is the western slope of South Mountain.

Cleavage dips steeper in the upper than the lower limb thus forming a fan which opens to the northwest. All parts of this fold participate and reveal an identical deformation plan: fold axes are nearly horizontal, cleavage dips southeast, lineation is in the cleavage plane normal to the fold axes, also dipping east. All formations including the volcanics participate. Intensity of deformation varies greatly within the fold depending on (1) physical properties of materials (2) location within the fold and (3) geographical location. Approaching South Mountain from the west intensity grows gradually, is strongest in the lower limb, decreases toward the crest and upper limb. Abrupt changes as would be expected in large-scale thrusting were not observed, the deformation seems to have been absorbed within a much wider complex. The fold is interpreted as a large "shear" fold as distinct from flexures. Deformation is thought to be due to laminar flow on subparallel planes. The presence of flow planes and the fact that oöids are extended at large angles to bedding show that stratigraphic thicknesses as now seen are not equivalent to depths of deposition. Calculations indicate that the latter amounted to less than one half of the present thickness.

The term Massanutten synclinorium is actually more applicable in the area of Massanutten Mountain near Luray, Virginia, where the structure is that of a simple synclinorium with a single major reverse fault (North Mountain fault) on the west. In Franklin County this fault splits into at least three faults which bring up three limestone belts in the Martinsburg shale terrane of the Great Valley (Figure 30) so that the structure is a complex synclinorium. Farther north, at Shippensburg, the synclinal structure apparently dies out, and the structure is that of a major complicated homocline dipping west off South Mountain and including Cambrian, Ordovician, and Silurian sediments. As noted previously the eastern limit of the Massanutten synclinorium is selected at the Carbaugh-Marsh Creek fault zone.

STRUCTURE OF THE MAPPED AREA

The field work accomplished to date demonstrates that the geology (Plate 1) is considerably more complex than that mapped by Stose (1909). It shows much more reverse faulting than Cloos (1941) was able to map at a smaller scale across the state line in Maryland, and confirms the structural patterns that Sando (1957) was able to map there in his detailed study.

A twofold structural division of the carbonates of the South Mountain anticlinorium is possible (Figure 31) based on different size of folds and their spacing as well as type of fault. Both are part of the same deformation plan although some of the Martinsburg is involved in the western zone and only carbonates are involved in the eastern zone. The eastern structural division includes most of the area of this report. Its western limit is the Carbaugh-Marsh Creek fault and its eastern limit is the limit of mapping. This area is dominated by five major, complex, southwest plunging anticlines and seven major reverse, east dipping faults. In the southeastern corner the Antietam Cove fault emerges from the South

Mountain volcanic core and causes a deviation from the deformational pattern of this structural division. The western structural division is a narrow zone about 2 miles wide near Kauffman and 2,000 feet wide at Greencastle, south of which it is overridden by the Carbaugh-Marsh Creek fault. It is limited on either side by faults related to the Carbaugh-Marsh Creek fault zone. This structural division is dominated by what are believed to be a series of closely spaced west dipping reverse faults cutting a major west facing anticlinal limb. Structural complexity increases northeast along strike of the zone.

Within the Massanutten synclinorium Martinsburg shales form a distinct, although not necessarily separate, structural entity from the limestones. There are insufficient outcrops and marker beds to decipher the structure, but in several large outcrops a type and degree of deformation can be observed that is distinct from the deformation of the carbonates in the two structural divisions of the carbonates in the South Mountain anticlinorium. The form of the Martinsburg folds differ from the more regular form of the carbonates. Flow cleavage is absent, and a fracture cleavage (Figure 28) related to flexure folding of strongly anisotropic beds is locally developed.

Folds

The folds, although complex, are characterized by a remarkably consistent geometry. They are of the cylindrical, flexure slip type in the western half of the carbonate terrane but more related to flexure flow or passive slip type in the eastern half.

On a regional basis there are six major anticlines (Figure 31) whose northern limit is the tear fault segment of the Carbaugh-Marsh Creek fault (Figure 31). The westernmost fold (VI) is cut off by the Carbaugh-Marsh Creek fault about 2 miles north of Greencastle but the other folds continue into Maryland where Sando (1957) has been able to map folds II, III, IV, and V as far as the Potomac River. Thus, these folds have a total mapped length of 27 miles and may continue for a considerable distance south of the Potomac River. Fold I does not appear as a major structure on Cloos' (1941) map of Washington County.

Major folds and associated subordinate folds all have the same geometric pattern (Figure 32); they plunge at an average of 25° S20°W well into Maryland. Regional flow cleavage, or S_1, striking at N20°E parallels the fold axis, and the few smear lineations present are normal to the fold axes and lie within the S_1 plane. Axial surfaces of the folds are vertical along the western edge of the carbonate terrane and gradually become east-dipping as the Blue Ridge is approached. Axial surfaces dip to the east at 50° in Elbrook Formation outcrops near Altenwald. They are, of course, part of the overturning of the South

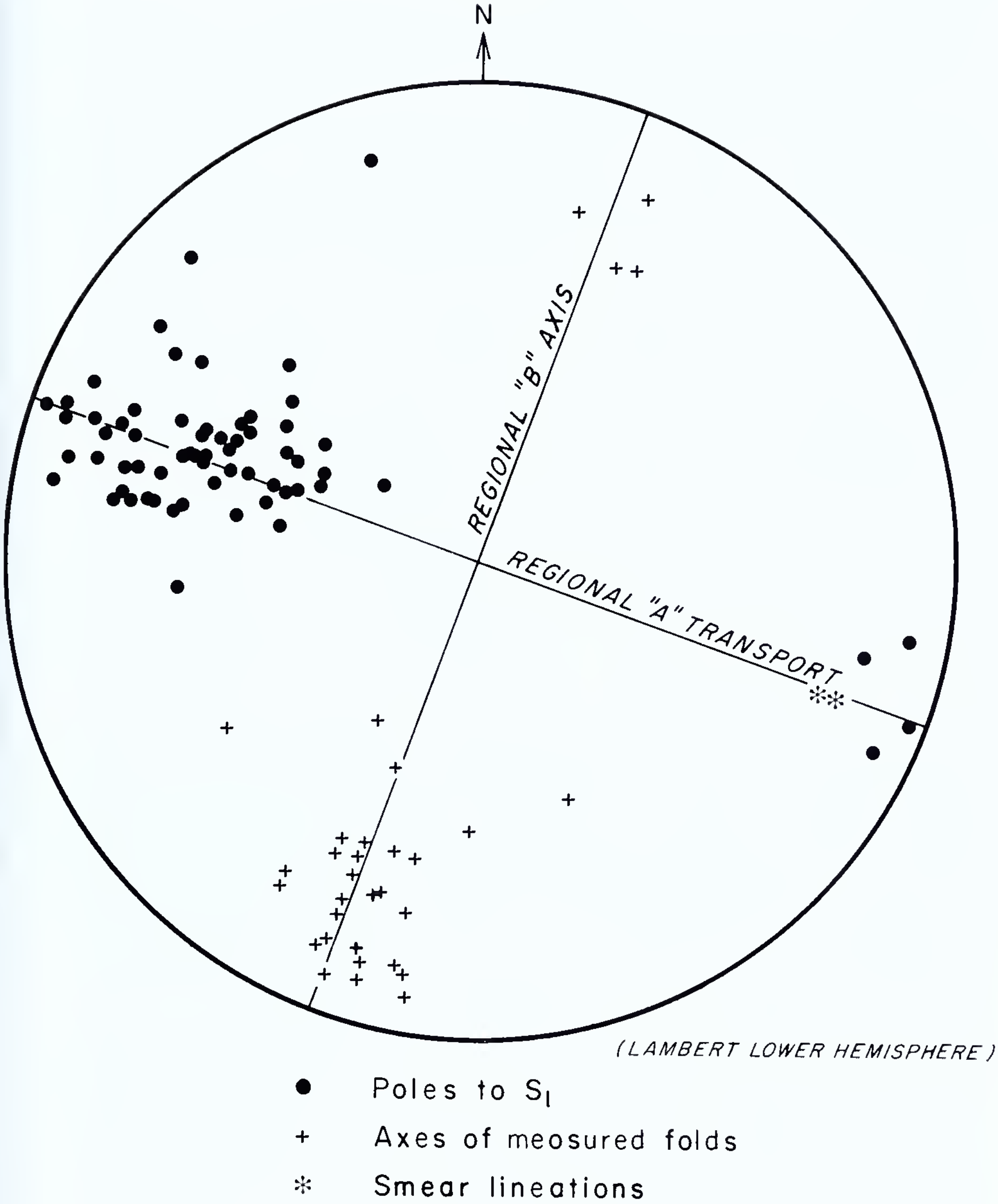


Figure 32. Synoptic petrofabric data of southeastern Franklin County.

Mountain anticlinorium as noted by Cloos (1947). This pattern is so consistent that one can determine position on a fold from any one outcrop by determining the dip of the beds even in the absence of internal evidence of top or facing. Any beds that dip to the west, are vertical, or are overturned to the east at high angles must be on the west facing limb of an anticline. Any beds that dip east at less than 50°, or somewhat more steeply in the west where axial surfaces are steeper, are on the east facing limb of an anticline. This relation is generally true even close to the major faults.

Most of the folds in units younger than the Elbrook Formation formed by interstratal slip during flexure folding; certainly the brittle shattering of faulted St. Paul and Beekmantown limestone at the Kauffman farm section, 6,000 feet west of Marion (MacLachlan and Root, 1966, Figure 10) do not indicate the conditions necessary for shear folding. The quarries of Valley Quarries, Inc. at New Franklin expose a thick sequence of

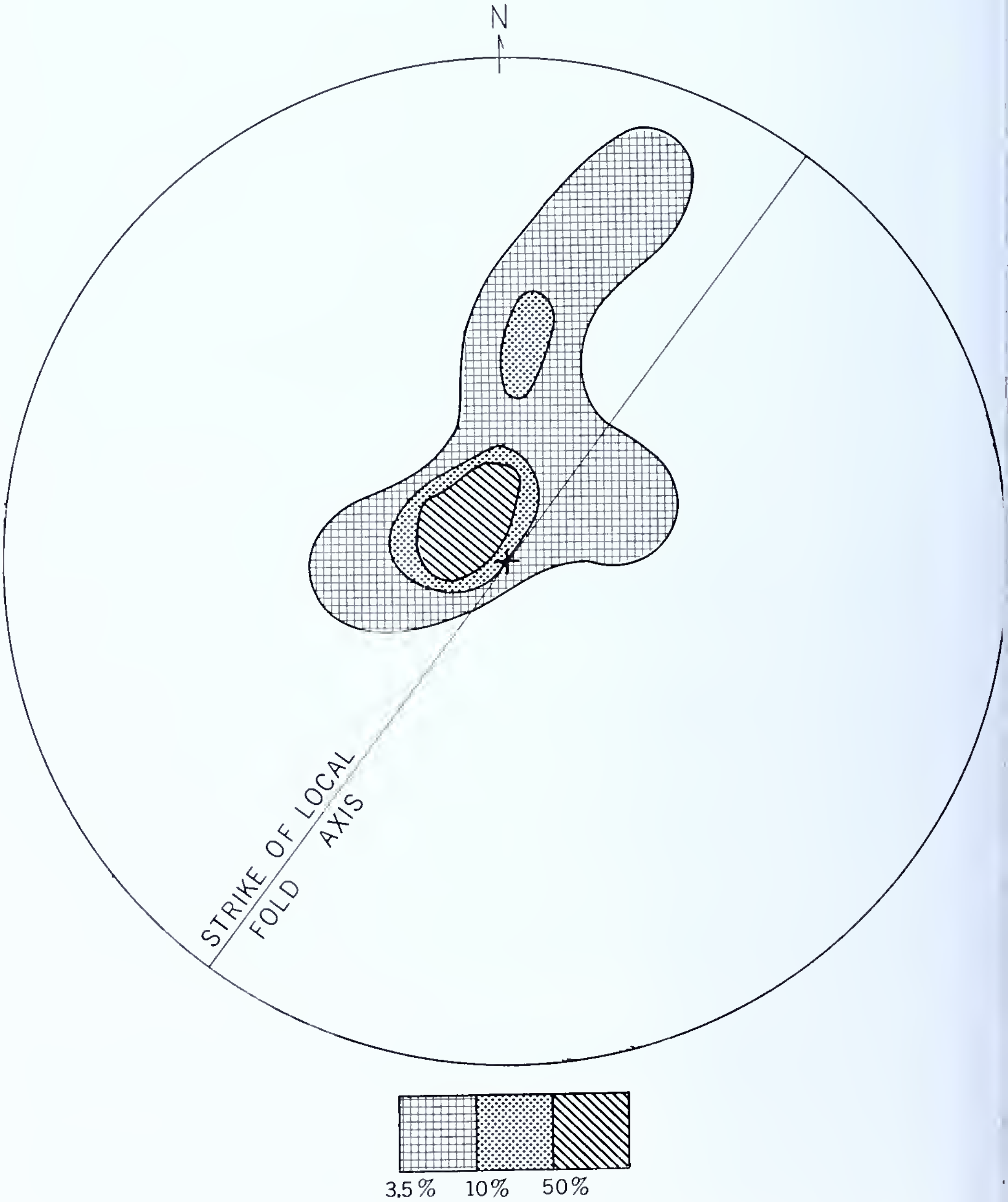


Figure 33. Petrofabric data from the Stonehenge Formation in the New Franklin quarry. Stereonet plot of slickensides on 12 bedding planes and 1 reverse fault surface, equal area lower hemisphere projection.

vertical Stonehenge limestone in which almost every bedding surface is slickensided, showing general interstratal slip congruent with fold kinematics (Figure 33). However, a few of the slickensides indicate motion in a horizontal or subhorizontal sense, parallel to the fold axis, demonstrating that more than simple folding of the sediments is involved. Subhorizontal transport may reflect movement during translation of the block bounded by the Carbaugh-Marsh Creek fault. Many of the bedding slip planes have extensive calcite slickensided surfaces with well-developed steplike breaks. On the footwall the abrupt step usually faces down. Flexure-slip mechanics would indicate that the abrupt step faces a direction opposite that in which the other block moved. This relationship has been observed elsewhere by Tjia (1964) and reproduced experimentally by Riecker (1965) who ascribes this to violent elastic rebound of stressed projectives on the sheared face during slip. In the excellent exposures of the Conococheague of Waynecastle Dairy the carbonates show little obvious effect of shear deformation, as the most delicate laminae (Figure 7) and bands (Figure 6) persist, undeformed by a penetrative flow cleavage.

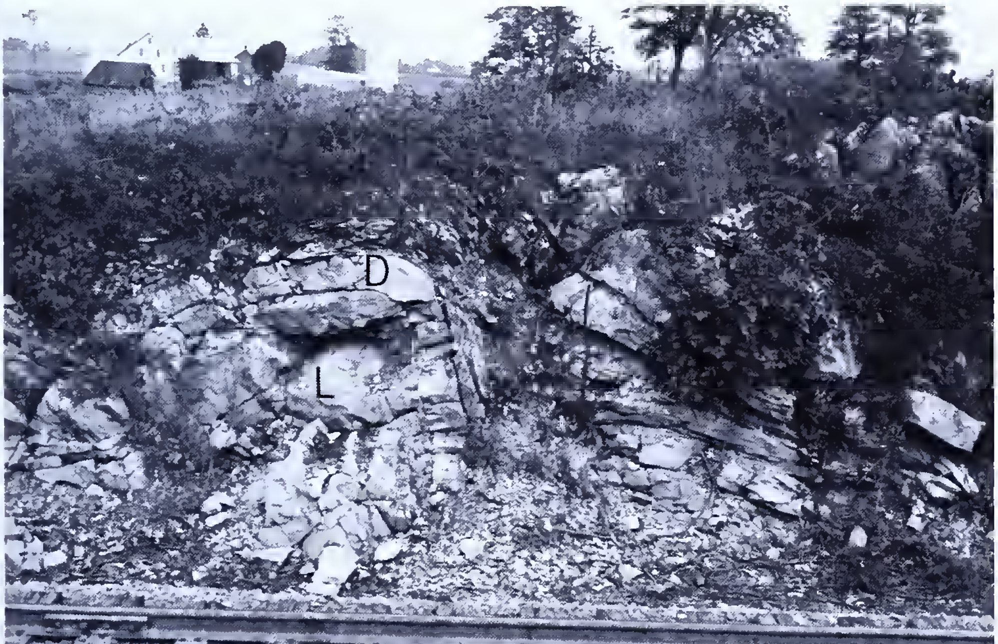


Figure 34. Flexure-slip fold developed in dolomitic stromatolite bed (D) which has maintained orthogonal thickness of one foot. Adjacent limestone beds (L) are more ductile and have deformed, in part, by passive folding. The stromatolites within the limestone beds, not discernible in the photograph, have been internally rotated into the plane of regional foliation—S_1. A high angle fault of small displacement occurs in the shale beds in the center of the outcrop. Photo is of the upper part of the Elbrook Formation in cuts of the Western Maryland Railroad near Guilford.

Farther east, in the cuts of the Western Maryland Railroad at Guilford, deformation of both flexure slip and shear types coexist. Horizontal beds in the upper part of the Elbrook Formation are located on the crest of a fold here. A small fold is locally developed (Figure 34). The anticline is well outlined by a bed of dolomitic algal limestone, of constant orthogonal thickness. More ductile, pure limestones in the core of the fold have flowed and been internally reoriented into the regional flow cleavage.

Exposures in cuts of the Western Maryland Railroad about half a mile northwest of Altenwald illustrate the type of deformation and folding in carbonates still closer to South Mountain. Vertical beds in the upper part of the Elbrook Formation are exposed here. In spite of the marked anisotropy resulting from interbedded limestones, silty dolomites, and limy siltstones, deformation has not been by interstratal slip but by slip across the beds (shear folding). The flow of bedding (S_0) in the regional cleavage direction (S_1) in this area is illustrated by Figure 35. Both

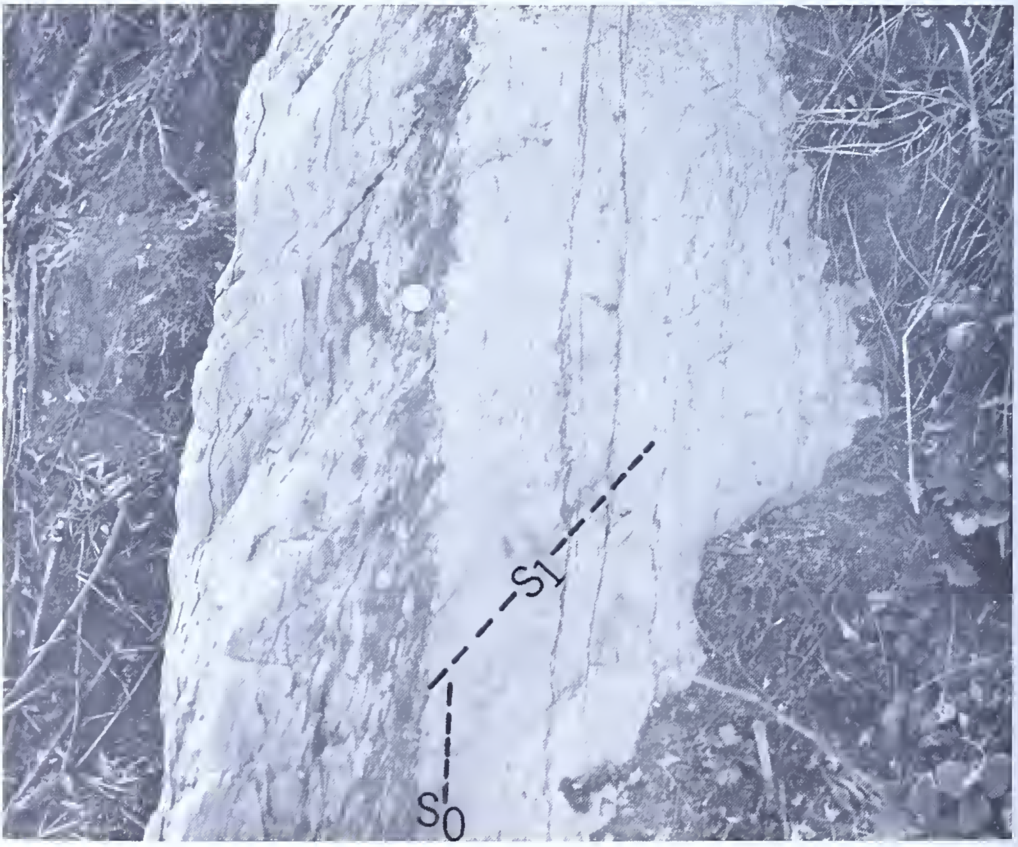


Figure 35. Intersection of bedding (S_0) and regional cleavage or foliation (S_1) in limestone of the Elbrook Formation. Note reorientation of S_0 into the plane of S_1. Photo taken in cuts of the Western Maryland Railroad near Altenwald.

amplitude and wave length of the folds is on a much smaller scale than in carbonates to the west. There has been considerable passive flow of the limestone with thickening on fold crests and attenuation on limbs. Intensity of local flow of limestone beds in this area is demonstrated by the development of second order flow folds within the bedding units, which have axial surfaces parallel to bedding rather than controlled by the regional cleavage which defines the axial surface of the larger fold.

Relatively competent beds such as dolomites and silty dolomites have in places maintained an approximation of bed normal thickness within a fold. These beds frequently exhibit closely spaced fracture cleavage, the surfaces of which show development of "gouge" (Figures 36 and 37) where there has been local movement along these surfaces; movement probably related to development of flow cleavage, but not in the plane of the flow cleavage. Some of the thinner beds show relations which indicate that the cleaved and "gouged" surfaces possibly may be rotational joints

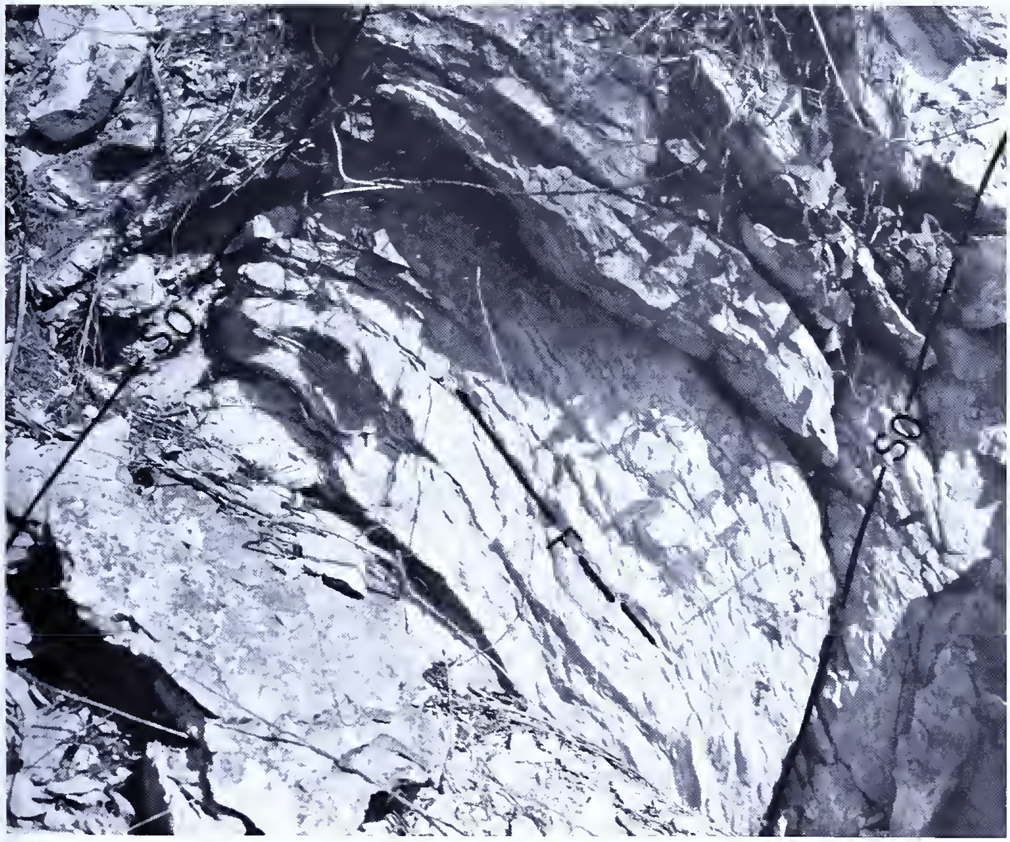


Figure 36. Development of gouge material in slightly curved fractures (F) in brittle silty dolomite beds (S_0) of the Elbrook Formation. Same locality as Figure 35.

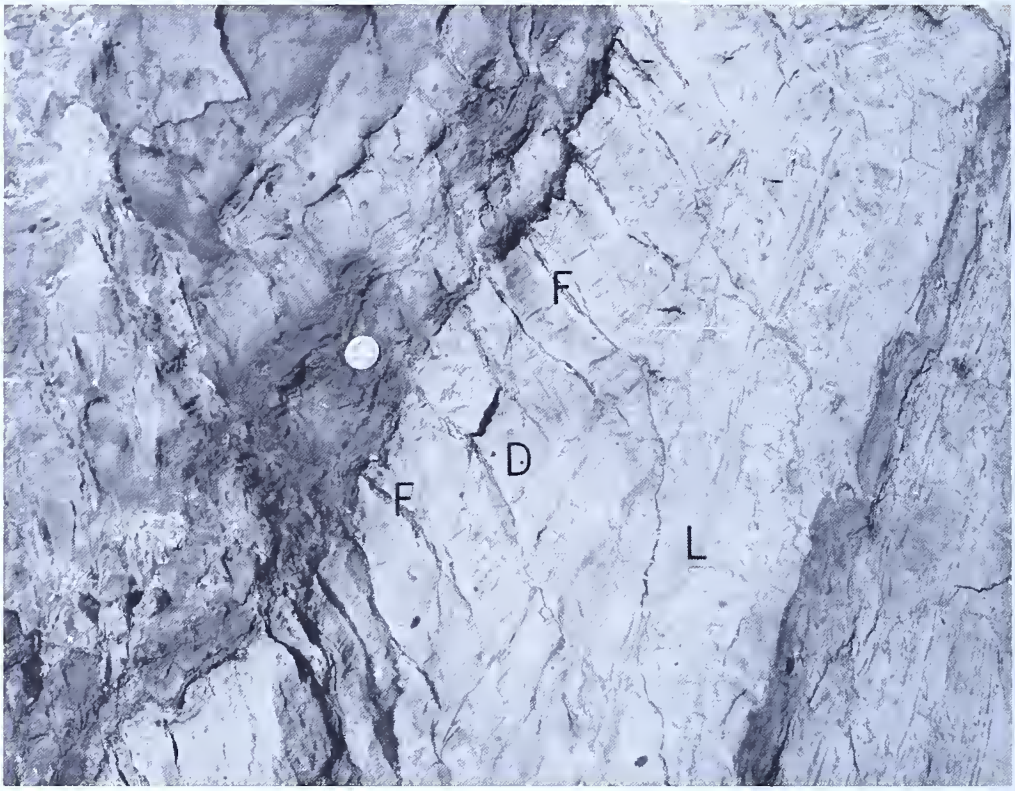


Figure 37. Development of gouge filled small fractures (F) (rotational or counter rotational joints?) in brittle dolomite (D) of the Elbrook Formation. Note absence of the fractures in the ductile limestones (L). Same locality as Figure 35.

modified by flow cleavage movement (Figure 37). Possible origin could not be determined in the thicker beds (Figure 36). Ductile faulting (faulting without loss of cohesion) is also present.

It would seem that close to the Blue Ridge, temperature and pressure conditions were such that a high mean ductility of the rocks was attained and passive folding was operative. The effect of passive folding diminishes gradually to the west from the Blue Ridge, and the impress of only moderate slip across layering would probably not be visible in field examination of a fold. To determine the actual amount of internal deformation, orthogonal thickness of a key should be measured around a fold. This would be a conclusive check on bulk rock deformation that Cloos (1947) determined only on the basis of extended oolites. It is of interest to note that oolite extension is considerable—52 percent (Cloos, 1947, Plate 9) near Altenwald, where shear folding is obvious, but it is only moderate (30 percent) at Waynecastle Dairy and the quarry at New Franklin where flexure folding appears dominant.

Faults

North-northeast trending faults are a conspicuous feature (Figure 31) of the carbonate terrane of southeastern Franklin County. While there is only one actual exposure of a major fault, occurring at the quarry at Greencastle where the St. Paul Group is thrust at a 60° easterly dip over the Martinsburg Formation (Figure 38), similar faults may be confidently inferred on considerations of fault and fold mechanics at the locus of a number of clear stratigraphic discontinuities. The east dip at this exposure is consistent with that of steep reverse faults exposed in the same belt of rocks to the south in West Virginia (Page and others, 1964). On this basis all northeast trending faults shown as solid lines on Figure 31, with the exception of the Antietam Cove fault, are considered to be east-dipping, high-angle reverse faults.

The system of faults in southeastern Franklin County is terminated at its northern end by an east-west tear fault which swings southerly at its western end and passes into the reverse fault zone defining the western

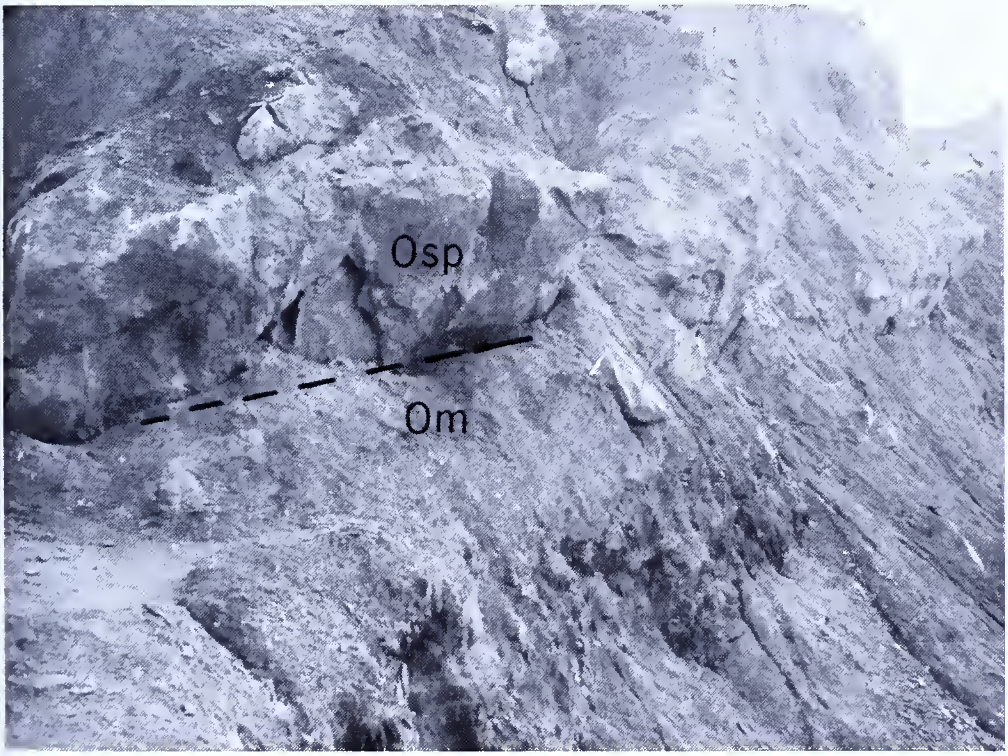


Figure 38. Limestones of the St. Paul Group (Osp) thrust, on a fault dipping at 60° to the east, over the shales of the Martinsburg Formation (Om). This fault is a segment of the Carbaugh-Marsh Creek Fault. The limestones are deformed in a brittle manner at the fault. The shales are ductile but only at the fault. Photo taken in the quarry about 1700 feet west of the square in Greencastle.

limit of the faulted carbonate terrane against the Martinsburg shale. This system has been designated the Carbaugh-Marsh Creek fault (Stose, 1932, p. 83). Sando (1957) was able to trace the segment of reverse faulting south to the Potomac River and further southward extension into Virginia is probable. Stratigraphic displacement is greatest near Williamsport, Maryland where Sando (1957) shows the lower Stonehenge Formation in thrust contact with the Martinsburg—a displacement of at least 1 mile. Actual movement at this and other parts of the fault could be considerably greater, however, as the structural relations between the carbonate belt and the shale belt of the Massanutten synclinorium are not entirely clear.

The Carbaugh-Marsh Creek fault zone delimits a large, high-angle thrust block that has moved over the Martinsburg shale. Units at least as old as the late Precambrian Catoctin greenstone are involved in this movement.

Faults shown by dashed lines on Figure 31 on the west side of the carbonate area are older than and are cut by branches of the Carbaugh-Marsh Creek System. These appear to be west-dipping, reverse faults.

At no place was there evidence of a decollement type fault. It has been postulated by Gwinn (1964) and Pierce (1966) that the Waynesboro and Elbrook Formations would be possible units along which detachment of the Paleozoic sequence could occur. Although exposure is poor in these units such features as continuity of topographic ridges over large distances and around structure, and rational outcrop belts are evidence against possible low-angle faulting. However, if a fault is present essentially along a bedding plane, such as the Martinsburg Tuscarora fault of Pierce (1966), then it would be obscured in the generally sparse outcrop.

Fault and Fold Mechanics

In order to consider those faults whose dip is not known, it is necessary to consider mechanical properties of deformed rocks and the domain in which this deformation takes place. The vertical sequence of the strata in the area is such that they are naturally divisible into four major structural lithic units (Currie and others, 1962, p. 670) based on the relative competencies of the rocks as observed in the field. The Chilhowee Group quartzites are considered to be relatively competent. The carbonates and shaly carbonates of the Tomstone, Waynesboro, and especially the Elbrook Formations are considered to be relatively incompetent. Carbonates of the Conococheague, Beekmantown, St. Paul, and Chambersburg units are considered as relatively competent. The Martinsburg Formation, composed largely of shale, is considered to be relatively incompetent. In terms of absolute mean ductility, for instance, the Tomstown-Elbrook sediments may be less ductile than the Conococheague-Chambersburg sediments, but the greater temperatures and pressures at which the former were deformed caused them to yield in a more ductile manner.

Because the Conococheague-Chambersburg structural lithic unit, some 9,000 feet thick, is best exposed it can be considered in some detail. As the unit was folded, where radius of curvature approached the thickness of a stratum, progressive increase in curvature of strata toward apices of the folds was accommodated by flexure-slip thrust faults that were kinematically concordant with interstratal slip (Price, 1965, p. 78), (Figure 39). Where there is marked anisotropy of the stratified sequence, especially where a relatively incompetent Martinsburg overlies the carbonates, symmetrically opposed overthrusting compensates for the lack of room in the core of a concentric fold. Cloos (1951, p. 161) shows an example (reproduced here as Figure 40) where movement on low angle thrusts away from the center of the syncline has squeezed a competent bed out of the crowded syncline center and onto the fold crest. He also cites an example at Sideling Hill (Cloos, 1951, p. 161) where the sense of movement is in opposite directions on both sides of the synclinal axes, i. e. thrusting onto the anticlinal crest. Gwinn (1964, p. 892) shows many similar examples in western and central Pennsylvania. Here symmetrical east and west dipping faults on the limbs of a fold lead to a depressed axial zone (Figure 41). The following explanation of this type of faulting is found in Gwinn (1964, p. 892):

> The symmetrical thrust faulting is a logical outgrowth of the concentric flexure folding in a special case: that is, in the folding of an anisotropic sequence of stratified rocks of strongly varying competency. In the early stage of folding of such an anisotropic sequence, internal movement is confined to flexure bedding-plane slip, with each bed shifting anticlineward relative to the underlying bed. At the same time, the trajectory of any unit volume of rock in the flanks is initially vertical, becoming suddenly horizontal. Thus, besides the pervasive anticlineward shift of an upper bed relative to a lower bed, there are also two flank blocks moving upward and inward onto the crest of the anticline.

The faults between the Carbaugh-Marsh Creek zone (Figure 31) are believed then to be west-dipping reverse faults of the type discussed above (Figure 42).

These faults might also be explained by an east-dipping normal fault generated early during folding. This indeed was the explanation that Stose (1909, p. 14) used in order to explain the relation of older beds on the west side of a fault, but his cross sections show folds completely at variance with the folds as they actually are. Considering the compressional history of the area and the regular form of the folds it is realistic to expect these faults to be west-dipping thrusts generated on the limbs of folds. If complimentary east-dipping faults were formed on the other side of the original anticline then this fault is now overriden by, or has become part of, the Carbaugh-Marsh Creek fault (Figure 31).

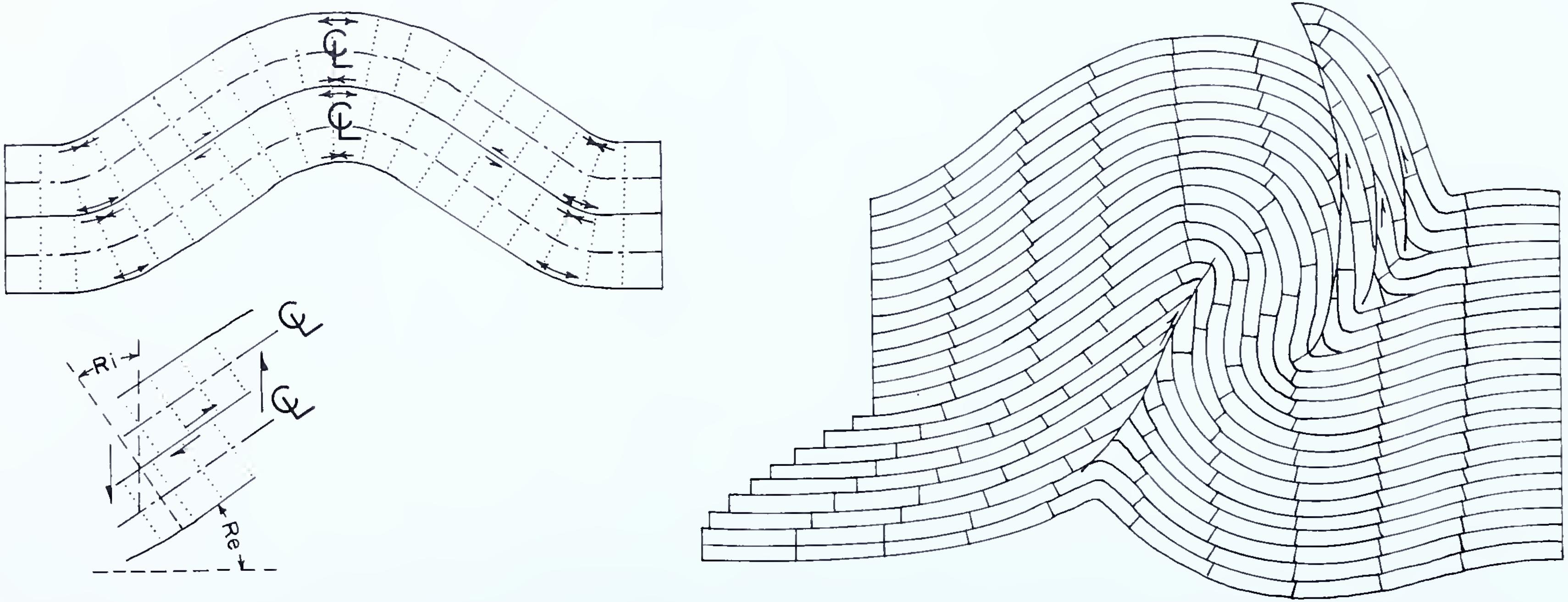


Figure 39. On the left, development of flexure-slip thrusts out of synclines. Strata are of uniform thickness and length. Interstratal slip is shown by reference lines drawn perpendicular to the bedding so as to divide the center line of each bed into ten equal segments. Progressive increase in curvature of strata toward apices of folds is accommodated, where radius of curvature becomes equal to the thickness of a stratum, by flexural-slip thrust faults that are kinematically concordant with the interstratal slip. From Price (1965). On the right, intra- and interstratal strains associated with flexural slip folding. Right section of a cylindrical fold. Dotted reference lines divide cross sections of strata into elements that were formerly rectangles of uniform dimensions symmetrically arranged about center lines (℄) of beds. Arrows show direction of compression on concave side and of extension on convex side of internal surface of no strain in each bed. Half arrows show direction of simple shear (interstratal slip) between beds. Offset element of left limb shows relationship between external rotation of a segment of a fold limb and interstratal slip within the segment. Large vertical arrows indicate direction of external rotation and *Re* is the angle of external shear. Smaller diagonal arrows indicate direction of complementary simple shear (interstratal slip) and *Ri*, the angle on internal shear, is dependent on *Re*.

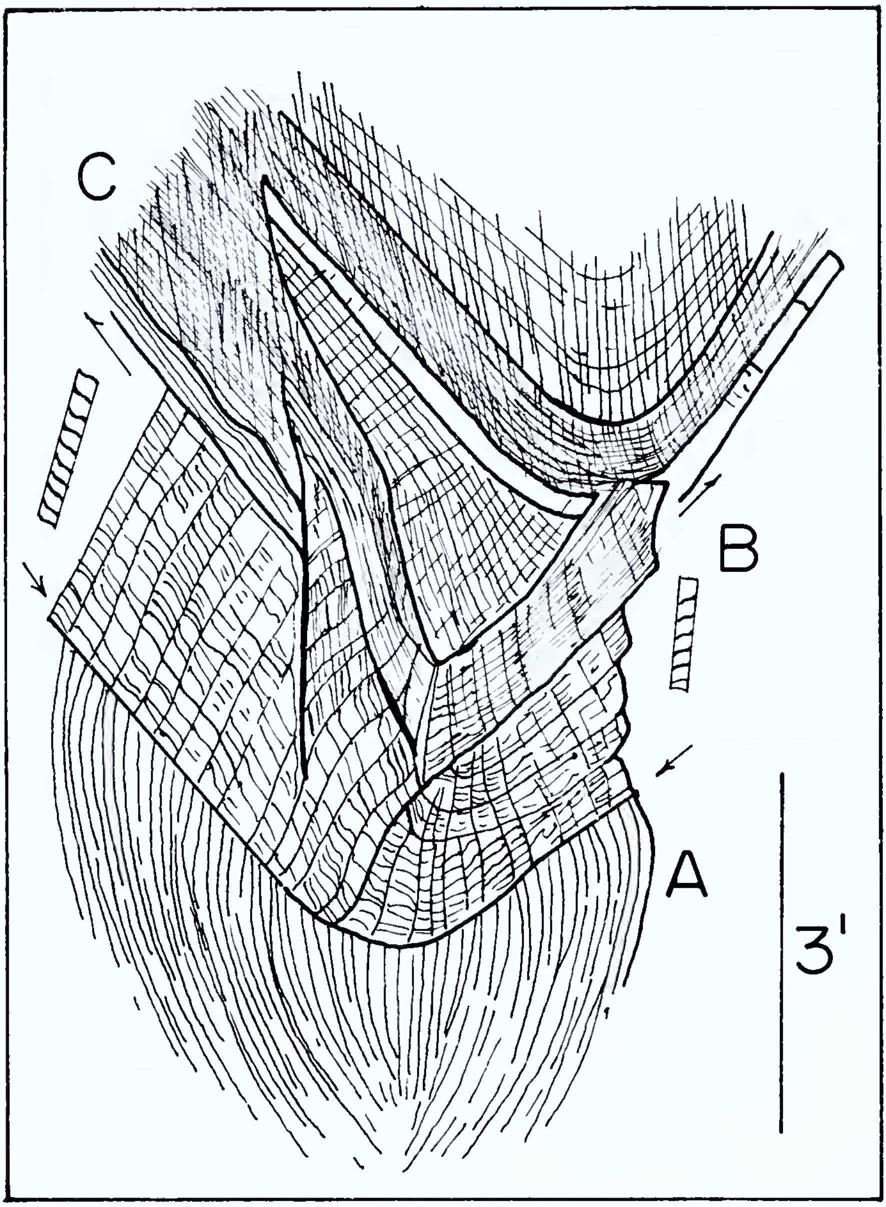


Figure 40. Thrusting out of syncline. In a sharply folded syncline portions of a relatively competent laminated dolomite bed (B) are crowded out and thrust into the soft shale (C) above. Relative movement of beds has produced small faults in the dolomite (B) beds by tilting of blocks. Round Top section opposite watchman's shelter. A: brown shale; B: laminated dolomite; C: shale. From Cloos (1951).

We must now examine what happens at a lower position in the folded sequence where there is less anisotropy and the carbonates are relatively competent. In this case lack of space resulting from the geometric impossibility of maintaining concentricity downward produces thrusting. It is known that in these cases the thrust will propagate itself through the asymmetric limb of the fold (DeSitter 1956, p. 241). The faults that merge with the east-dipping Carbaugh-Marsh Creek fault are generally located on the eastern limb of major synclines with younger beds on the

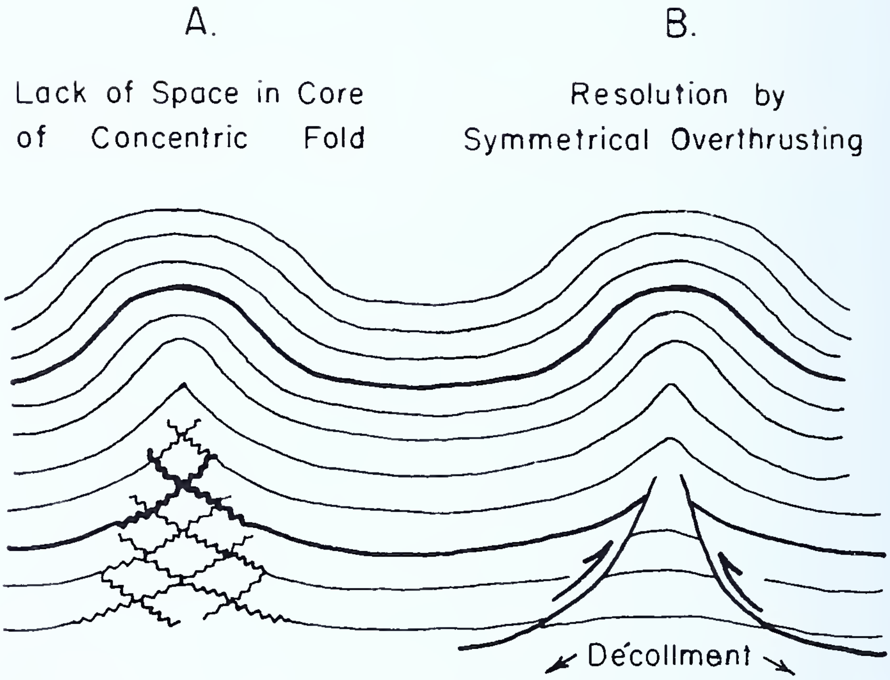

A.
Lack of Space in Core of Concentric Fold
B.
Resolution by Symmetrical Overthrusting
Décollment

Figure 41. Thrusting out of synclines. Symmetricol overthrusting os o consequence of room problem in the core of o concentric fold; A, Room problem in the core of a concentric fold; B, Resolution of thrust of limbs over axial depression in the tightened core zone of an onticline, with persistence of concentric folding above. From Gwinn (1964).
(Reproduced by permission of the Geological Society of America)

west side of the faults, (Plate 1); hence, they are also assumed to be east-dipping reverse faults that have sheared up along the subvertical to overturned west limbs of anticlines (Figure 42).

Faults are notably absent in the area of the map which largely represents outcrop of the relatively incompetent structural lithic unit of the Tomstown-Elbrook Formations. This probably results from yield by passive folding rather than flexure folding. These units could 'flow' into the cores of concentric folds developed in the overlying, relatively competent Conococheague-Chambersburg structural lithic unit. Hence, there was no problem of space to be resolved by faulting as there was no maintenance of geometric concentricity in these less competent units.

The Antietam Cove fault in the southeastern part of the area (Figure 31) is least understood of all the faults in the area. Apparently it does not continue in Maryland as Cloos (1941) does not show it on the geologic map of Washington County. It probably passes into bedding at the Elbrook-Waynesboro contact. Although this fault has older beds on the west side of the fault where stratigraphic displacement is greatest, it is probably not related, in origin, to the type of fold mechanics that produced the west-dipping thrusts near Kauffman (Figure 31). This fault probably formed late and is related to movement of the fault block bounded by the Carbaugh-Marsh Creek fault or still later Triassic border faulting.

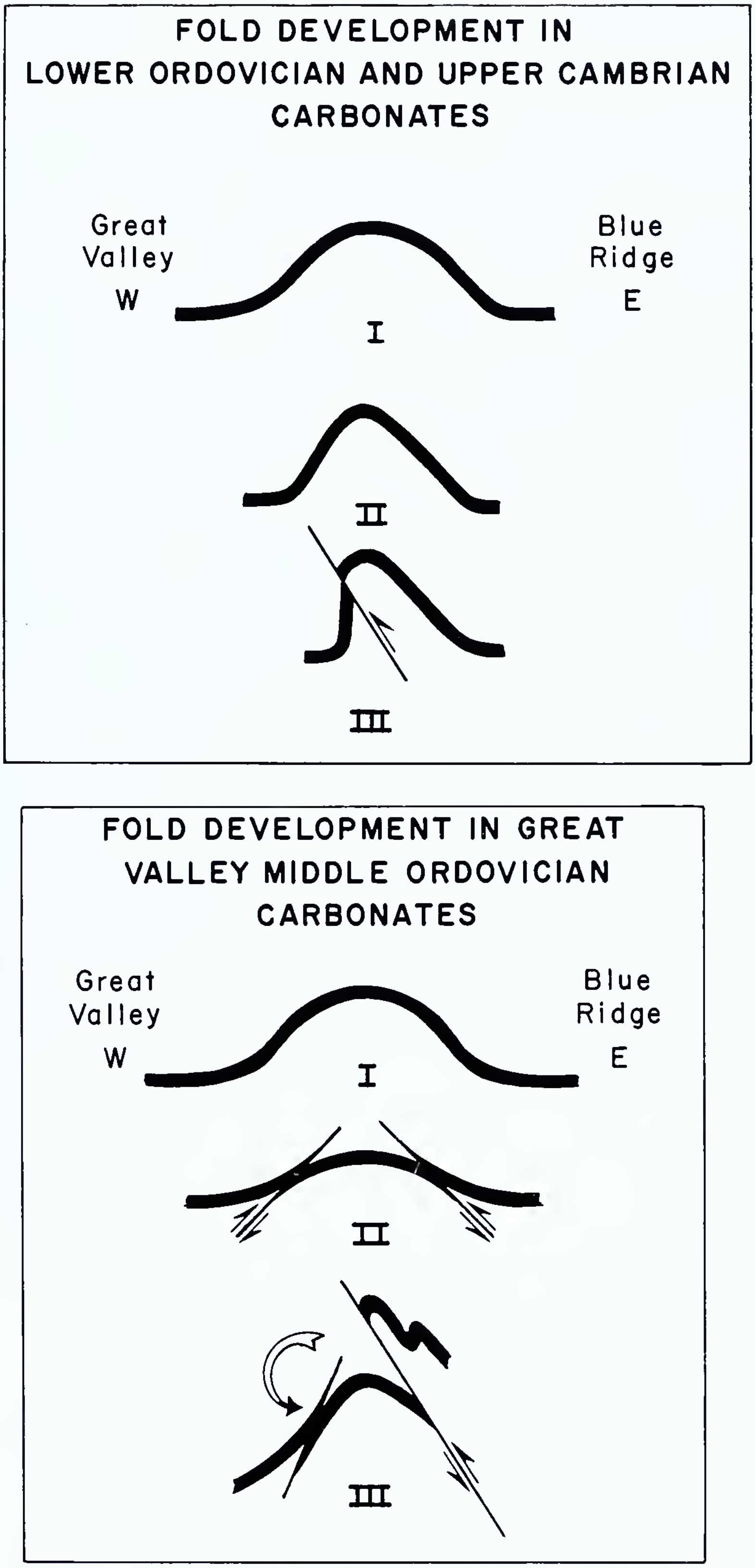

FOLD DEVELOPMENT IN LOWER ORDOVICIAN AND UPPER CAMBRIAN CARBONATES
Great Valley
W
Blue Ridge
E
I
II
III
FOLD DEVELOPMENT IN GREAT VALLEY MIDDLE ORDOVICIAN CARBONATES
Great Valley
W
Blue Ridge
E
I
II
III

Figure 42. Development of structures on the east side of the Great Valley.

DEFORMATION OF THE MARTINSBURG FORMATION

Deformation in the Martinsburg is not unlike that in Cambro-Ordovician sediments when it is considered that this flysh sequence is strongly anisotropic and probably was subjected to a smaller stress. However, it should be noted that there are actually few exposures of the Martinsburg large enough to indicate the type of deformation. The most striking aspect within the Martinsburg is the complete dominance of interstratal slip and paucity of S_1 cleavage that is so well developed in the limestones. Close to the limestone contact some S_1 surfaces, harmonious with the S_1 in the adjacent limestones are present, but farther west S_1 is virtually absent. Strong fracture cleavage is developed (Figure 28) especially in the thick graywacke beds of the sandy portion of the Martinsburg.

The geometry of the Martinsburg folds is similar, but on a much reduced scale, to that of the limestones. The folds are asymmetric to the west and plunge to S20°W at 25° close to the limestone outcrop belt. In the middle portion of the shale valley the folds do not plunge, and close to the upfaulted belt of limestone that passes through Williamson all folds plunge to the northeast. This reversal of plunge direction, as compared with folds of the South Mountain anticlinorium is one principal feature of the Massanutten synclinorium.

The Carbaugh-Marsh Creek fault and related faults that separate the limestone from the shale is not a boundary between two different tectonic units. The shales adjacent to the limestone still retain some imprints of the South Mountain anticlinorium deformational plan. Considering the poor exposures of shale it is not inconceivable that a major fault passes through the shale valley juxtaposing southwest-plunging structures on the east against northeast-plunging structures on the west. If no fault is present then the change in plunge across the valley probably becomes related to a larger problem—arcuation of the Appalachians.

STRUCTURAL HISTORY

The structural history of this area is derived by considering the deformation processes in the Conococheague-Chambersburg structural lithic unit. An evolutionary sequence in the tectonic history is postulated below:

I. Gentle folding of the beds.

II. Continued folding, with thrusting onto the anticlinal crest, perhaps symmetrically opposed, in the upper part of the sequence where a relatively incompetent structural lithic unit overlies the carbonates.

III. Continued folding and development of asymmetry, shearing (reverse faulting) through the steepened west limb permitted tightening in the core of the fold. Stages II and III are closely related temporally.

IV. Major block adjustment. This involved translation of the entire block bounded by the Carbaugh-Marsh Creek fault zone including the Catoctin greenstone. The block moved westward a considerable distance; certainly more than the 2 miles indicated by immediate offset of the contact of the Catoctin greenstones across the fault (Figure 30). This is concluded because major structures in the Chilhowee Group cannot be matched across the fault, and it is perhaps possible that several widely spaced Chilhowee folds were overridden to bring this block to its present position.

Movement across the block diminished westward as some of the lateral translation was dissipated along the pre-existing east-dipping reverse faults concentrated between folds II-IV, increasing the original displacement across these faults. The folds were oversteepened or overturned even more to the west. The Carbaugh-Marsh Creek fault block then overrode the early west-dipping thrusts between Chambersburg and Greencastle truncating most of them west of Greencastle. In places it may have followed along the complimentary east-dipping fault if the early thrusting was symmetrically opposed (Figure 42). The west-dipping faults locked during this event and no movement took place, but they, and the west-dipping anticlinal limb, were externally rotated and oversteepened, so that they are now probably near vertical or even overturned and dipping east. Movement along the Carbaugh-Marsh Creek fault induced a splay between Greencastle and Chambersburg so that there is a reverse fault between the Martinsburg shales and Ordovician limestones along the east branch of Conococheague Creek.

V. Movement of the Antietam Cove fault. If the Antietam Cove fault is related to the main movement of the Carbaugh-Marsh Creek fault block, then it probably formed in the late stage of this movement. If the fault dips east, then it is a normal fault produced by extension as the Carbaugh-Marsh Creek fault block moved west. If it dips west at a high angle, then it is a reverse fault that served to 'pop-up' the terrain between Waynesboro and Greencastle. If it dips west at a low angle, it marks the 'heel' of a detachment.

STRUCTURAL PROBLEMS

Some fundamental problems must still be resolved by future work. Among these are:

I. Was there only one period of deformation? Analysis of fold kinematics (Figure 32) and absence of an S_2 surface would indicate only a single deformation. In the Piedmont multiple deformations have been recognized (Freedman and others 1964, and Lapham and McKague, 1964) and two periods of deformation have been recognized in the immediate Valley and Ridge (Pierce and Armstrong, 1966). In the Lebanon Valley allochthon multiple deformation is also recognized (MacLachlin and Root, 1966).

Several stages are recognized in the deformation of the Cumberland Valley autochthon. If these are secular rather than continuous stages, then folding and minor faulting might represent an early period of deformation and translation of the Carbaugh-Marsh Creek fault block might represent a later period of deformation. If there actually was multiple deformation in the Cumberland Valley the geometry of the fold pattern was nearly homoaxial in both instances.

II. When did the deformation or possibly deformations occur?

III. Do the detachment surfaces recognized by deep drilling in the Appalachian Mountain section of the Valley and Ridge continue into the Tomstown-Elbrook relatively incompetent structural lithic units where they have subsequently been folded?

IV. Are the Blue Ridge Mountains autochthonous at depth? Although surface mapping indicates that all exposed rocks were deformed as a single coherent entity, is there, perhaps, a major thrust at depth along which the Blue Ridge Mountains have moved westward?

V. Does the Antietam Cove fault merge within the Carbaugh-Marsh Creek fault in the Catoctin greenstones near Cashtown? Are these faults then part of a gently southwest-dipping detachment along which a block of Martinsburg-Catoctin rocks have 'slid' west exposing behind them a 'rooted' zone of Cambrian-Catoctin rocks.

MINERAL RESOURCES

INTRODUCTION

Mineral production in Franklin County in 1964, for stone plus sand and gravel amounted to the value of about $1,500,000 (Kerr, 1966). In the area of this report limestone, shale, quartzitic sandstone, and greenstone are the rock types present. One of the purposes of this report is to point out the mineral potential of such rocks.

MINERAL HISTORY

Prior to the development of sophisticated mining techniques, several varieties of minerals were extracted from the area by small groups of miners in local operations. Among those minerals mined were iron ore, barite, and white clay.

Significant quantities of limonite were mined throughout the area in the mid 1800's especially east of Montalto at the foot of the mountain. The ores are closely associated with the contact of the Antietam sandtone and Tomstown dolomite. That these ores are supergene is unquestionable but their source is somewhat problematical. Hack (1965) has suggested that the ores are derived from minerals once thinly disseminated in certain beds in the Waynesboro and Tomstown Formations and protected from erosion by the talus and alluvium that is washed over and around them from the Blue Ridge Mountains. Stose (1909, p. 17) ascribes the source to Antietam or Waynesboro sandstones and shales, impregnated with iron, which is dissolved by surface water and precipitated in the porous talus at the foot of the Blue Ridge. Large tonnages of iron ore are undoubtedly still present under the colluvium at the foot of the Blue Ridge, but cannot be mined economically at present. Manganese ore is commonly associated with iron deposits of the type previously described, but none has been discovered in the mapped area although some have been reported to the northeast.

Barite has been mined in the area (Stose, 1909, p. 18) but in a desultory manner. Deposits are quite local, and the barite occurs as a cement in a limestone breccia.

White kaolin clay, very pure and siliceous, associated with the iron ores along the west base of South Mountain (Stose, 1909, p. 18) has been mined for use in the manufacture of paper, paint, and chinaware. It is presently being mined near Mt. Holly Springs, Cumberland County, for use in white cement manufacture. According to Stose (1909, p. 18), the clay occurs as a sedimentary bed at the base of the Tomstown Formation. If, indeed, this is so then there should be considerable reserves of this material along the west base of South Mountain, the location of which would require considerable drilling.

The limestones, sandstones, and shales which compose the bedrock in this area were also utilized for other purposes. These are discussed in the succeeding section in which recent information is considered in view of current requirements.

PRESENT POTENTIAL

The common use of most of the minerals in the area will be considered in the light of their local geologic conditions.

Magnesium and Magnesium Compounds

Dolomite is used for the production of magnesium metal, and magnesium compounds such as refractory magnesia, basic magnesium carbonate, or magnesium chloride. No rigid specifications exist for dolomite for these purposes but generally it should contain more than 40 percent $MgCO_3$ and less than 1 percent each of SiO_2, Fe_2O_3, and Al_2O_3.

Some of the dolomites present in the mapped area apparently do have the purity required for the purpose cited above, although information is sparse. The two units which contain abundant amounts of dolomite are the Tomstown Formation and Pinesburg Station Formation. The Tomstown is imperfectly known because most of it is covered, but from the results of two chemical analyses (Table 1) from iron mines of the 19th century and 12 acid insoluble residue (silica, iron, alumina, etc.) analyses (Figure 43), impurities, mostly in the form of SiO_2, detract from its utility. Two Tomstown samples, however, had acid insoluble residues of about 1 percent indicating fair purity. It is conceivable that prospecting in the covered areas of the Tomstown Formation might yield deposits of pure dolomite.

Four chemical analyses (Table 1) and 48 acid insoluble residue analyses (Figure 43) indicate that the Pinesburg Station Formation contains more SiO_2 and less dolomite than the Tomstown Formation. The presence of interbeds of limestone within the dolomite sequence has decreased the proportion of $MgCO_3$; it is not a mineralogical change. From these data it would appear that the Pinesburg Station Dolomite is not suitable for purposes requiring a low silica content.

To the south, in West Virginia, Grimsley (1916, p. 35) reports $MgCO_3$ of about 36 to 41 percent and SiO_2 content of from 1.8 to 6.0 percent from 6 samples of what is the Pinesburg Station Formation. Near Winchester, Virginia, Edmundson (1945, p. 37) reports 40 percent $MgCO_3$, 5.3 percent SiO_2 and 1.2 percent combined Al_2O_3 and Fe_2O_3 from 350 feet of dolomites from the Pinesburg Station Formation. Thus for a

Table 1.—*Partial chemical analyses of dolomites in southeastern Franklin County.*

Sample	*1*	*2*	*3*	*4*	*5*	*6*
SiO_2	2.16%	4.09%	2.16%	5.39%	9.68%	6.68%
Al_2O_3	0.94	4.09	0.67	0.99	1.76	1.23
Fe_2O_3			0.32	0.51	0.92	0.58
P_2O_5	0.03	0.03	0.01	0.02	0.03	0.23
S	—	0.01	0.01	—	—	—
$CaCO_3$	54.39	51.74	63.02	64.38	51.23	59.78
$MgCO_3$	42.69	43.44	32.47	27.47	33.53	29.65

1. Mine No. 4, Mont Alto Iron Co., Mont Alto, Tomstown Fm., After McCreath 1881.
2. Shiery Quarry, 1.5 miles northeast of Mont Alto, Tomstown Fm., After McCreath 1881.
3. Zone 30′ thick at top of Rockdale Run Fm., Kauffman, Pa. section, After Swartz & Thompson (1958).
4. Zone 40′ thick below sample 3.
5. Zone 40′ thick below sample 4.
6. Zone 40′ thick at top of Rockdale Run Fm., Marion, Pa. section, After Swartz & Thompson (1958).

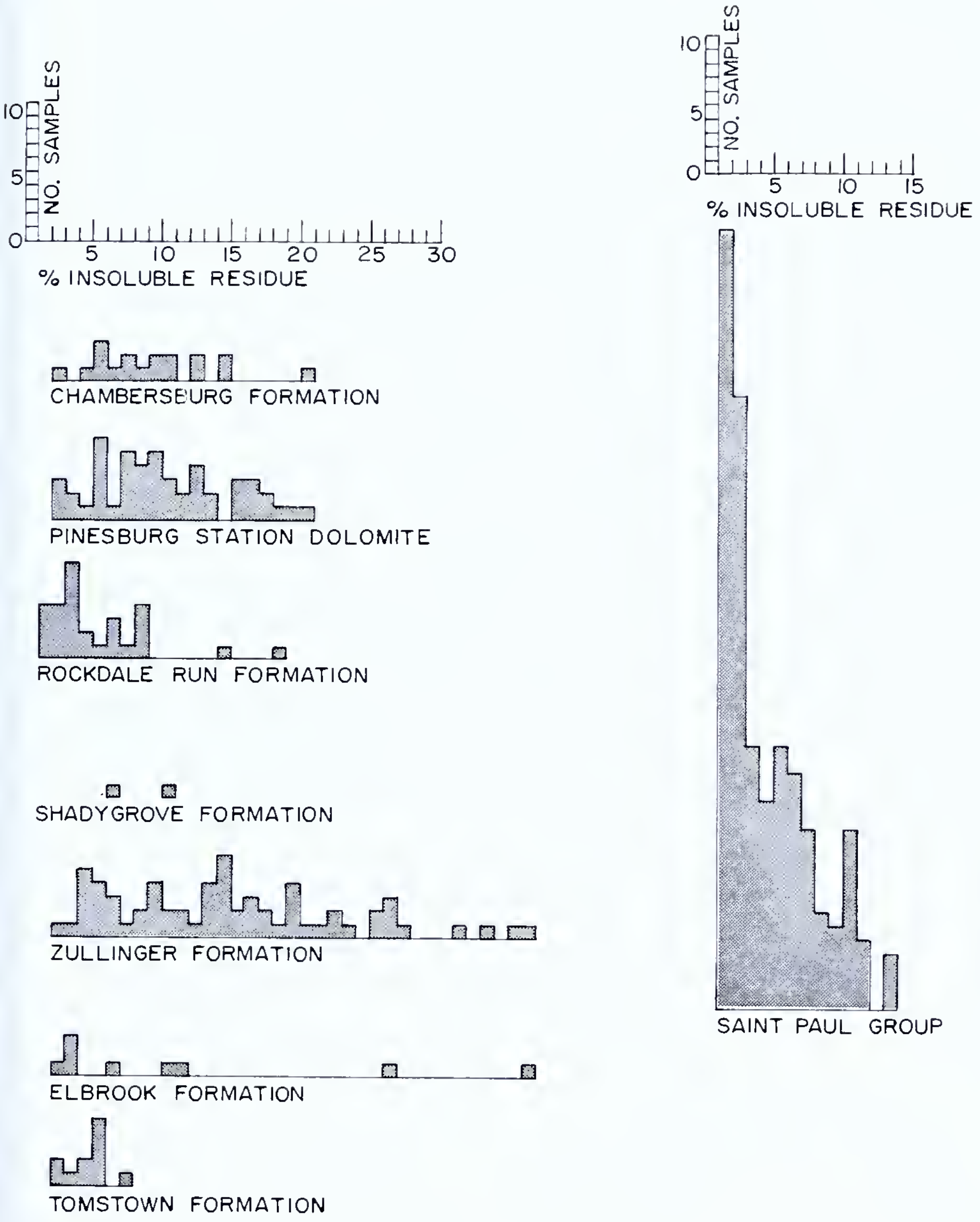


Figure 43. Amounts of acid insoluble residues in carbonates, principally limestone, from various formations in Franklin County.

considerable distance along the Great Valley it lacks certain economic utility and there is no indication that the grade of dolomite will improve to the north.

Dolomite of the Tomstown and Pinesburg Station Formations meets the requirements for agricultural dolomites. The principal requirements for a rock of this type (see Table 2) are that $CaCO_3$-$MgCO_3$ should total 85 percent, apparently SiO_2, Al_2O_3, and Fe_2O_3 content is not important. As the Tomstown and Pinesburg Station dolomites are normally more than 90 percent carbonate (Table 2) they fulfill the necessary requirements.

Table 2. *Chemical requirements for uses of limestone and dolomite**

Uses	*Chemical requirements*
Limestone for Portland cement	Magnesium carbonate ($MgCO_3$) not more than 6.3%. Minimum calcium carbonate ($CaCO_3$) content varies from plant to plant depending on the availability of other raw materials.
Limestone for lime (high calcium)	Calcium carbonate ($CaCO_3$) content not less than 97%, preferably 98% or more.
Magnesium carbonate for lime (magnesium)	Magnesium carbonate content should be between the limits of 21 and 31.5%.
Limestone and magnesian limestone for steel flux (blast furnaces)	Silica (SiO_2) less than 5%. Alumina (Al_2O_3) less than 2%. Magnesium carbonate less than 8% to less than 31%. Phosphorus content should not exceed 0.01%.
Limestone for steel flux (open hearth)	Calcium carbonate ($CaCO_3$) content should exceed 98% but some limestone as low as 97% $CaCO_3$ is sometimes accepted.
Dolomite for refractories	Magnesium carbonate ($MgCO_3$) not less than 37.5%. Silica (SiO_2), ferric oxide (Fe_2O_3) and alumina (Al_2O_3) not to exceed 1% each.
Limestone for general chemical use	Calcium carbonate ($CaCO_3$) content should exceed 98% but limestone as low as 97% $CaCO_3$ is sometimes used.
Agricultural limestone	Minimum of 85% $CaCO_3$.
Agricultural dolomite	Calcium-magnesium carbonate content should total at least 85%.
Limestone and dolomite for glass	Ferric oxide (Fe_2O_3) not more than 0.05%. Calcium carbonate ($CaCO_3$) content should exceed 98% in case of limestone, or 98% calcium-magnesium carbonate, in case of dolomite.
Limestone for paint and filler	In general the calcium carbonate content should exceed 96% but the magnesium carbonate ($MgCO_3$) no greater than 1%. Other maxima are: Fe_2O_3—0.25%, SiO_2—2.0%, and SO_3—0.1%.

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* This table indicates chemical requirements as standardized by the various consuming industries.

Chemical Grade Limestone

High calcium limestones are used in diverse ways. Portland cement, lime, steel fluxstone for open hearth and blast furnace, general chemical use, glass manufacture, paint filler, and agricultural limestone are but some of the common uses of high calcium limestone. Chemical requirements of the limestone utilized in these industries is summarized in Table 2. For uses such as high calcium limestone, steel fluxstone, chemicals, glass, and paints and filler, the $CaCO_3$ should be in excess of 90 percent and the SiO_2 correspondingly low. The only limestones that meet these requirements are those in the St. Paul Group. An idea of the purity of carbonate in the area can be gained by an examination of Figure 43, which shows the amount of acid insoluble residue present in the different formations from both random samples and measured sections.

Limestones of the St. Paul Group near Marion and Kauffman were studied in considerable detail by Swartz and Thompson (1958), and the Pennsylvania Railroad also has kindly furnished data concerning exploration carried out by them in the early 1950's in the area. The chemical analyses derived from these studies are presented on several triangular diagrams. The principle of triangular diagrams is shown in Figure 44. As none of the sediments analyzed are in the magnesitic field only partial diagrams are shown—i.e. with apical 100 percent $CaCO_3$ but only 50 percent $MgCO_3$ and 50 percent noncarbonate. This permits greater accuracy in plotting the data. A composite stratigraphic section of the St. Paul Group has been constructed (Fig. 45) which shows the stratigraphic distribution of the analyses. Figure 46 shows results of chemical analyses from vaughanites at the base of the St. Paul. Figure 47 shows the results from a 180-foot interval above the vaughanites. Figure 48 represents the results from about 300 feet near the middle of the St. Paul Group, and Figures 49 and 50 illustrate the results from the uppermost vaughanite beds at the top of the St. Paul Group.

The vaughanites at the base and top of the St. Paul Group (Figures 46 and 49) are low in $MgCO_3$, SiO_2, Al_2O_3, Fe_2O_3, P_2O_5 and S and contain sufficient $CaCO_3$ for use as chemical grade limestone etc. Beds near the top of the St. Paul Group (Figure 50) are not of chemical grade but could be used in the manufacture of cement or steel fluxstone. The remainder of the St. Paul although it might possess the requirements for cement or fluxstone (Figures 47 and 48) contains variable amounts of chert which causes undue wear on grinding machinery. Locally, this chert might be absent but a diamond drilling program would be necessary to ascertain this. Any contemplated quarrying operation in this area should be thoroughly investigated because of the effect of the complex geologic structure increasing quarrying costs.

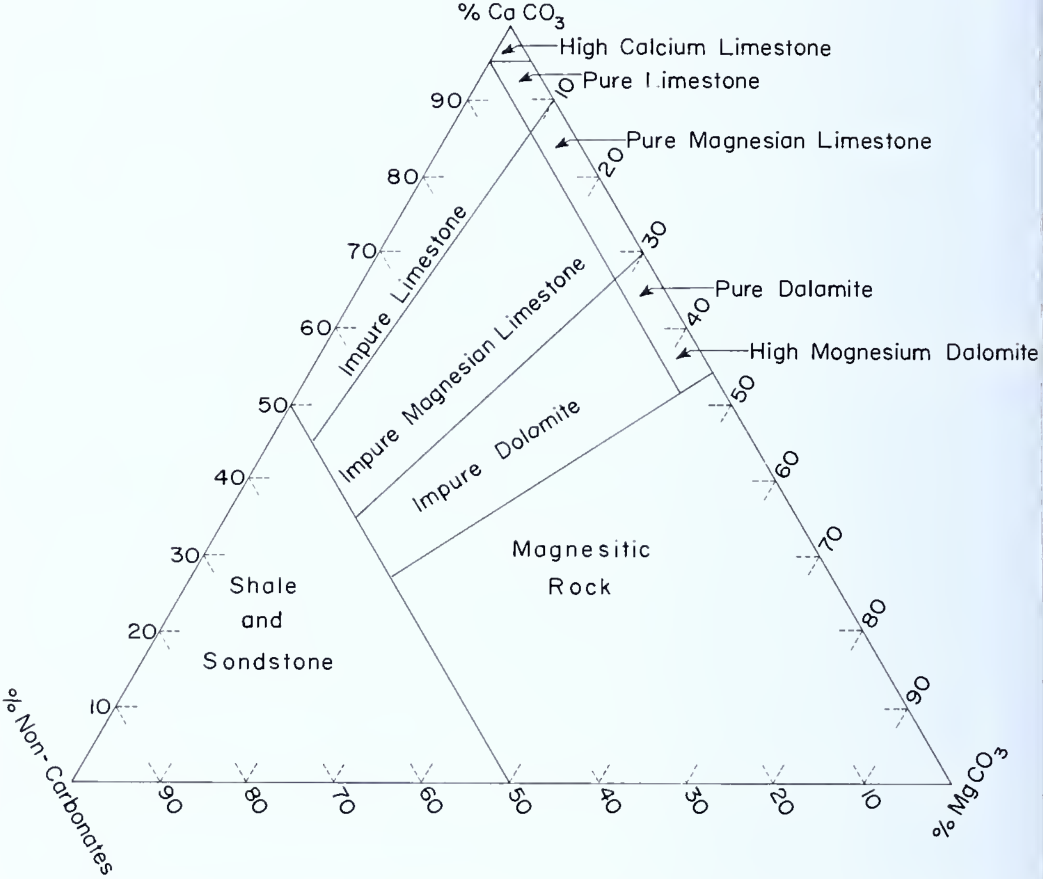


Figure 44. Triangular diagram showing fields occupied by the various types of carbonate rock. The diagram is so constructed that the upper angle of the triangle represents 100 percent $CaCO_3$, the lower right-hand corner 100 percent $MgCO_3$ and the lower left-hand corner 100 percent insoluble constituents, i.e., silica, alumina, and iron oxides. Any limestone (or dolomite) analysis which adds up to 100 percent can be plotted on the diagram as a single point, whose distance from each corner represents the percentage of that constituent. After Gray (1951).

During the early stages of this study, it appeared that the chert nodule-bearing, pink marbleoid, limestone beds at the base of the Rockdale Run Formation might be of sufficient purity that they could be utilized for high calcium limestone. Three samples from middle portions of the unit at the measured section near Antrim Church were, therefore, chemically analysed and the results are presented in Table 3.

These data indicated the beds are not of high-calcium limestone grade. However, they are of sufficient purity for cement purposes but the presence of abundant chert nodules in the basal beds and probable presence of isolated chert nodules adjacent to the analysed beds detracts from their utility.

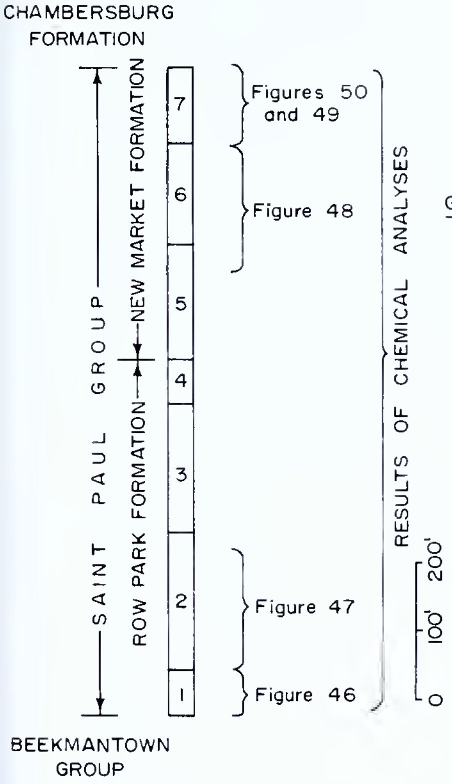
Analyses are available from the Stonehenge Formation at the operations of Valley Quarries at New Franklin by courtesy of the operators.

Ten samples across most of this unit are shown in Table 4 and Figure 51. The presence of the abundant SiO_2 and low $CaCO_3$ preclude use of the rock for any chemical purpose except cement manufacture. Actually by carefully controlled mixing of shale and other additives, parts of the Tomstown Formation, Waynesboro Formation, Conococheague Formation, Rockdale Run Formation, and Chambersburg Formation could serve as a cement rock.

Calcareous marls occur at several places in the mapped area. Although some deposits are of fair size and contain 85 to 90 percent $CaCO_3$ none has been exploited to date. These deposits are discussed by Miller (1934, p. 388).

Coarse Aggregate

Material classed as coarse aggregate by the Pennsylvania Department of Highways includes stone, gravel, and slag of which only the first is produced in Franklin County. To meet highway specifications stone, whether it be type A, B, or C, shall be prepared from tough durable rock, free from slaty texture or cleavage planes. Classification of stone is based primarily on weight loss during the Los Angeles Rattler test—the loss is



GENERALIZED LITHOLOGY

7. Vaughanites
6 Dark grey, fine-grained limestone and vaughanite, some yellow dolomite
5. Dark grey, fine-grained limestone, striped, abundant black chert
4. Mottled cherty limestone
3. Dark grey, granular, thick-bedded limestone with argillaceous laminae
2. Dark grey limestone, mottled, sparse chert, Maclurites
1. Vaughanites

Figure 45. Composite of stratigraphic sections of the St. Paul Group near Marion and Kauffman, Pennsylvania (after Neuman, 1951) and stratigraphic position of chemical analyses by various authors.

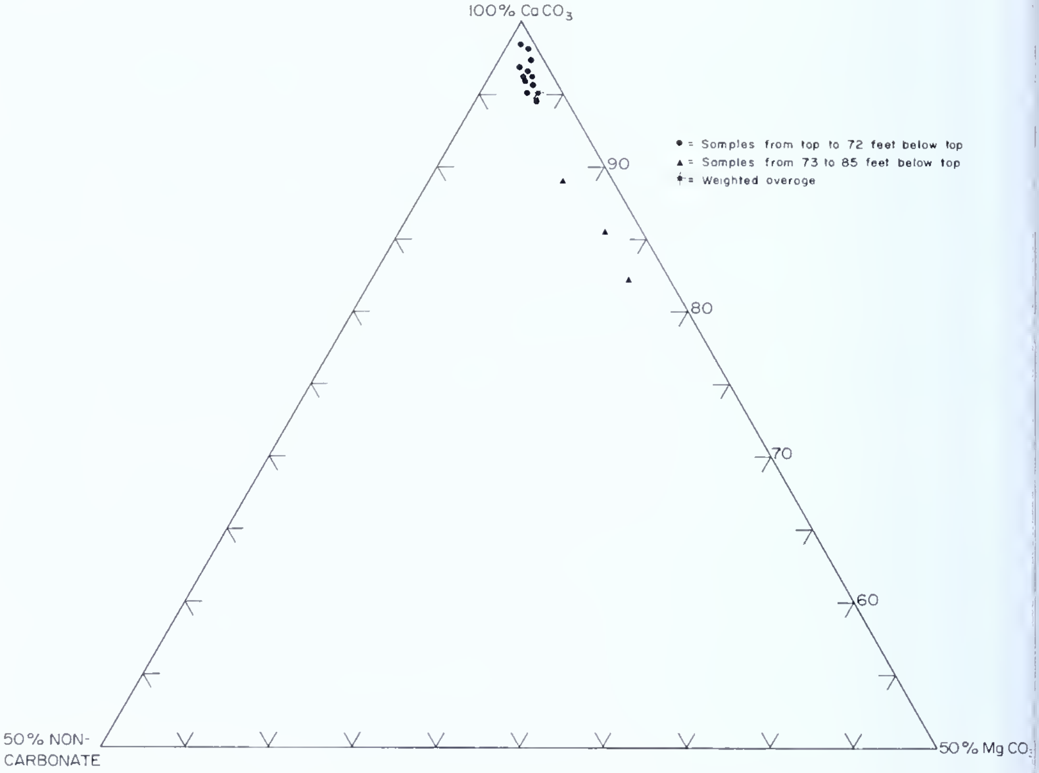


Figure 46. Partial chemical analyses of 14 samples from 85 feet of vaughanitic limestone at the base of the Row Park Formation. Samples collected from outcrops at Marion and Kauffman sections. Data from Swartz and Thompson (1958).

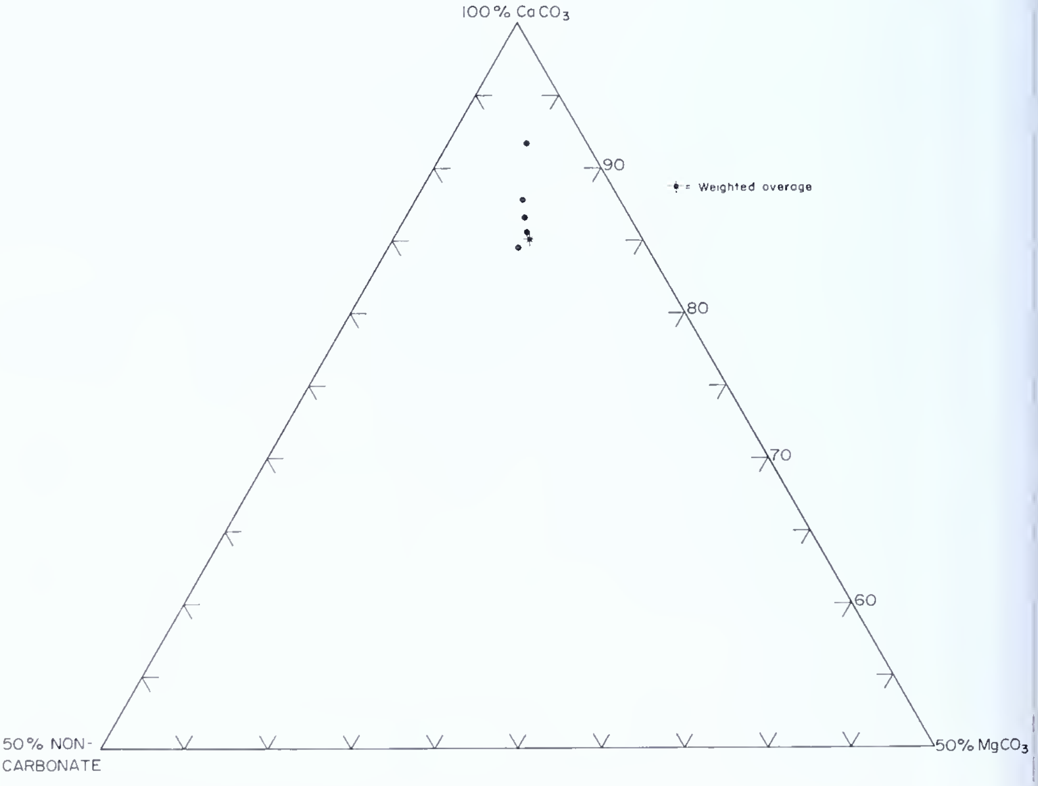


Figure 47. Partial chemical analyses of six samples from 180 feet of limestone above the basal vaughanites, Row Park Formation. From outcrop at the Marion and Kauffman sections. Data from Swartz and Thompson (1958).

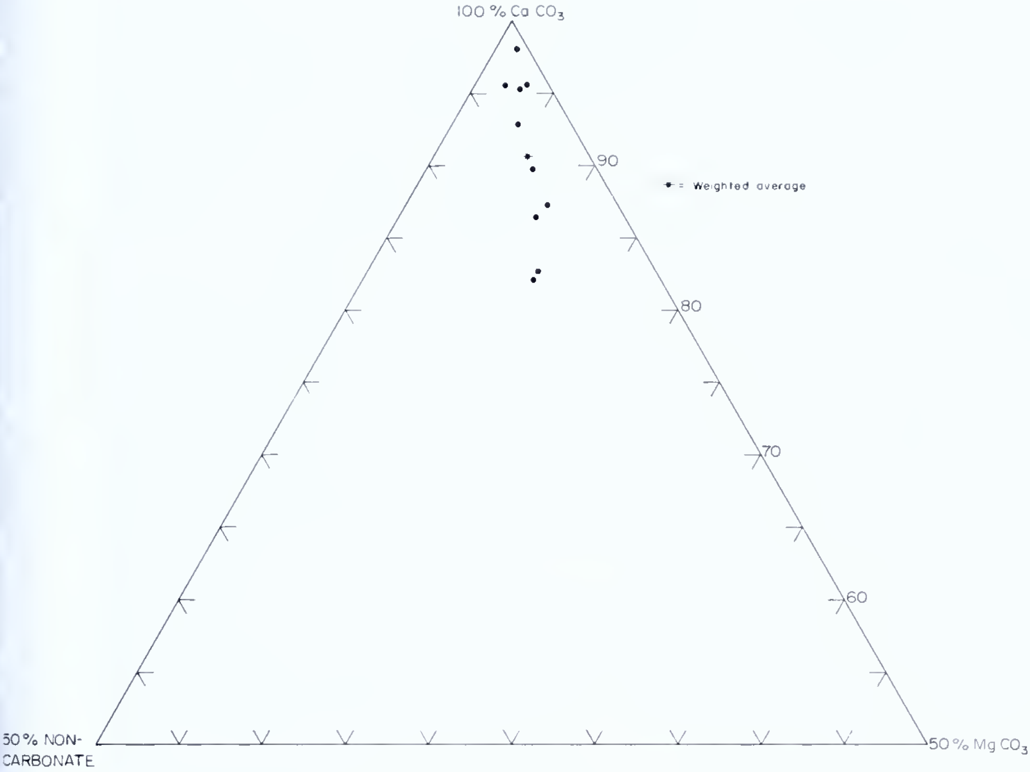


Figure 48. Partial chemical analyses of ten samples from the middle of the New Market Formation. From outcrop at the Kauffman section. Data from Swartz and Thompson (1958).

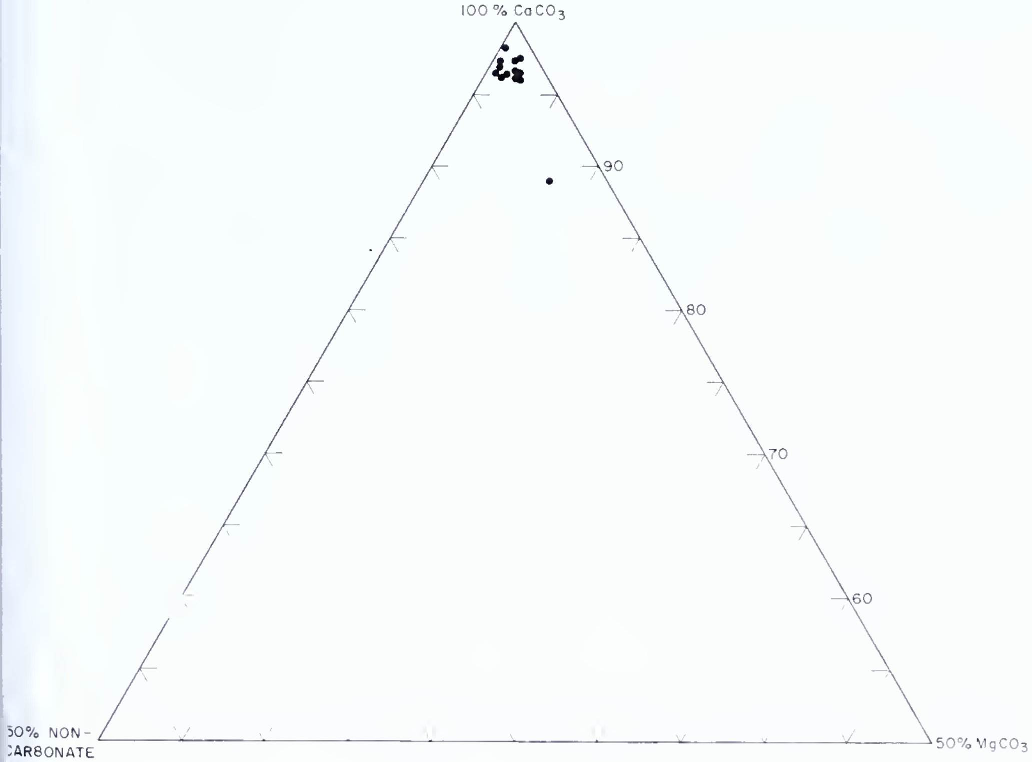


Figure 49. Partial chemical analyses of 12 samples from the upper 115 feet of the New Market Formation, one mile west of Kauffman. Samples at 5-10 foot intervals. From unpublished data of the Pennsylvania Railroad.

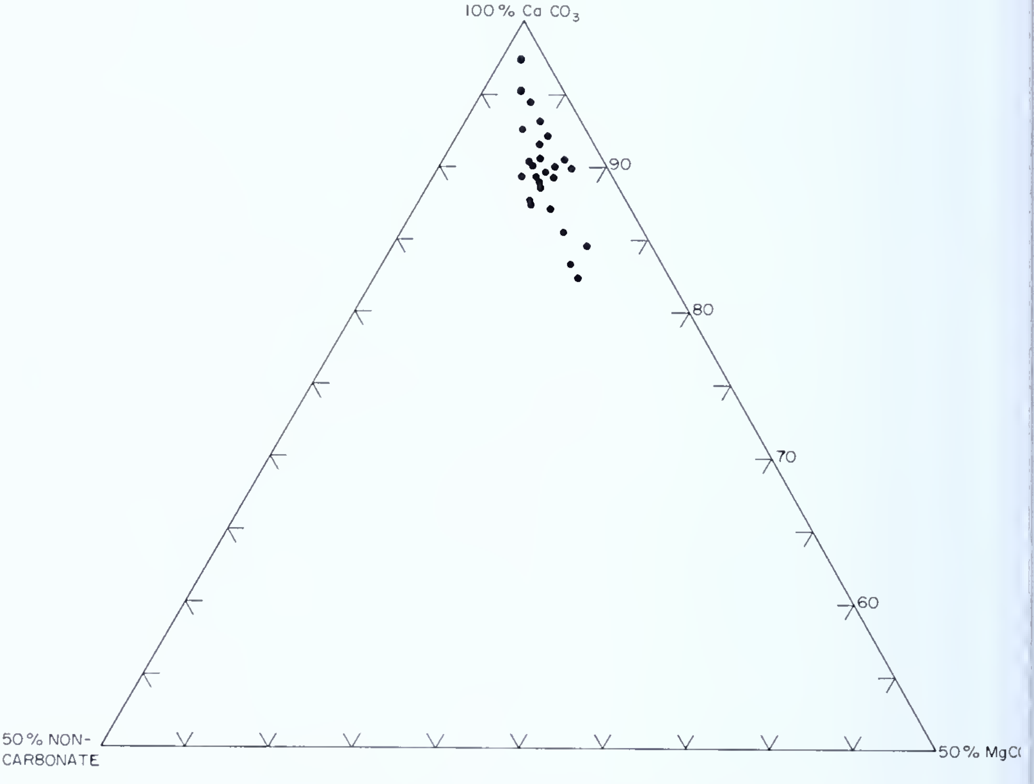


Figure 50. Partial chemical analyses of 26 drill hole samples of the upper portion of the New Market ormation, one mile northwest of Kauffmon, Pennsylvania. The drill hole probably passed through aulted strata. From unpublished data of the Pennsylvania Railroad.

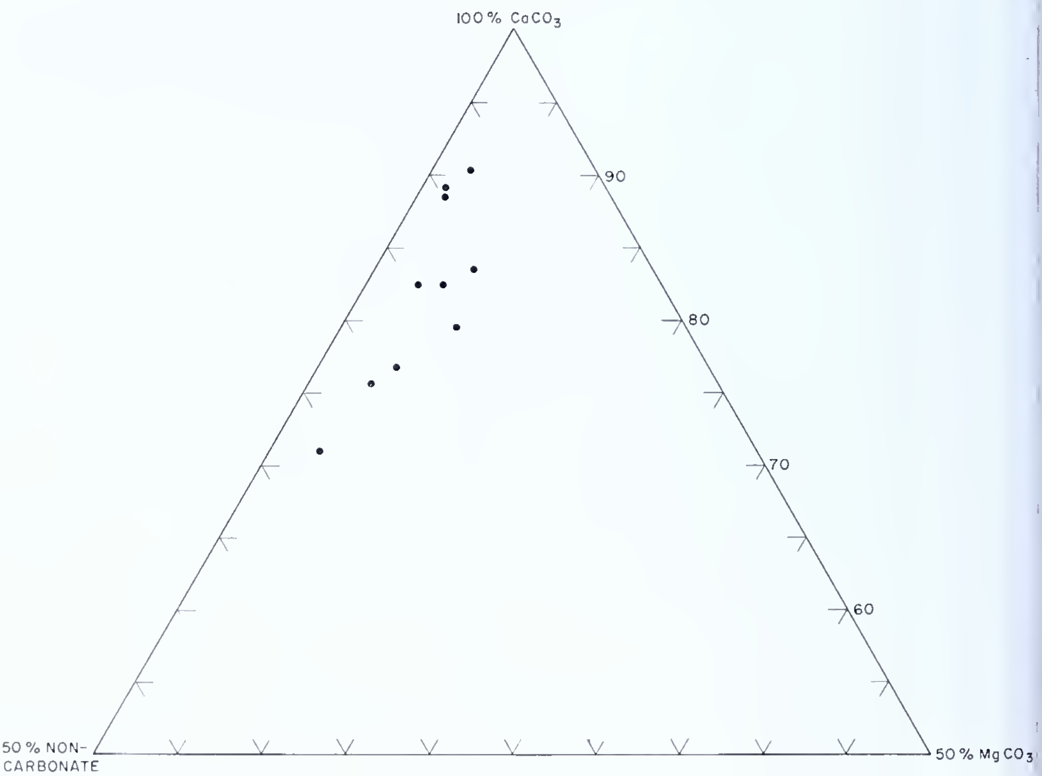


Figure 51. Partial chemical analyses of ten samples of the Stonehenge Formation across the south face of Valley Quarries Inc. workings at New Franklin, Pennsylvania.

Table 3.—*Partial chemical analyses of basal beds, Rockdale Run Formation. From measured section near Antrim Church, Franklin County.*

Sample	*1*	*2*	*3*
SiO_2	5.03%	2.81%	5.51%
Al_2O_3	0.70	0.34	1.14
Fe_2O_3	0.42	0.31	0.37
P	0.003	0.004	0.003
S	0.009	0.005	0.005
$CaCO_3$	91.75	95.94	91.62
$MgCO_3$	1.10	1.50	1.86

NOTE: Sample 1 was collected 180 feet above the base of the Rockdale Run Formation, sample 2 at 255 feet and sample 3 at 281 feet.

progressively greater from type A to type C. In addition, more deleterious substances such as shale and clay lumps are permitted in type C than type A stone.

Two quarries in the mapped area, the Valley Quarries, Inc. operation near New Franklin and Appalachian Stone Division of Martin-Marietta Corp. near Zullinger, produce class A stone. The former produces from the Stonehenge Formation and the latter from the Zullinger Formation. Other quarries in the county that produce type A stone are located in the Chambersburg Formation and St. Paul Group. All the carbonate formations in the area should be capable of meeting requirements for type A stone. The basal part of the Rockdale Run locally has intercalated shale beds that decrease the soundness of the stone to type C. In addition chert horizons at the base of the Rockdale Run, and in the Shadygrove Formation and the middle of the St. Paul Group might yield a type C rather than type A stone as well as causing mechanical difficulty in the crushing operation.

Table 4.—*Partial chemical analyses of Stonehenge Formation. Samples collected across south face of quarry at New Franklin.*

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SiO_2	5.46	9.62	11.60	10.50	8.26	15.06	13.66	17.88	7.80	7.06
Al_2O_3 Fe_2O_3 P	2.12	3.60	3.02	3.34	2.32	5.34	4.76	7.06	1.84	2.54
$CaCO_3$	90.25	81.50	81.47	78.50	82.15	73.47	75.58	68.00	88.07	87.32
$MgCO_3$	2.26	4.58	2.28	6.78	5.69	3.23	4.32	2.78	1.37	1.37

Fine Aggregate

Material classed by the Pennsylvania Department of Highways as fine aggregate for use other than in bituminous mixtures, consists of hard, durable grains thoroughly cleaned by washing, free from lumps of clay and all vegetable and deleterious substances. Three categories: natural sand, manufactured sand, and artificial sand are recognized. Only manufactured sand which results from the controlled mechanical breakdown of conglomerate rock into its natural individual grain sizes is produced in the area. Fine aggregate is divided into types A, B, C, and D with type A containing less silt, possessing a greater strength ratio, and less percentage loss in soundness tests than types B, C, and D.

The Antietam Formation is mined by the Mount Cydonia Sand Co. 2 miles east of Fayetteville. It yields type A fine aggregate, and as this formation is of uniform lithology, aggregate of this type should be available along the front of the Blue Ridge to the Maryland line.

Some of the river gravels and sand are capable of yielding both fine and coarse aggregate but to date they have not been prospected.

Dimension Stone

Under the category of dimension stone are included building stone, monumental stone, paving stone, curbing, and flagging. Physical properties to be considered are hardness and workability, strength, porosity and specific gravity, and durability. Other factors to consider are texture and color which influence the appearance of a rock.

Utility of the rocks for dimension stone has been discussed by Stone (1932, p. 161-164). He cites the abundant local use of various limestone for building stone; red metarhyolite and greenstone have been used sparingly for building stone; Cambrian quartzite has been used in Caledonia Park to build some homes; and even cobbles from mountain wash have been used in a few bungalows. Curbing and flagging from the thin sandy beds at the top of the Waynesboro Formation have been used in the town of Waynesboro. In the writer's opinion many of the limestones have sufficient beauty and the physical requirements for a popular building stone of the ashlar type.

The reddish to light-gray marbleoid limestones at the base of the Rockdale Run Formation near Antrim Church and at several other places (Plate 1) and certain reddish marbleoid limestone horizons in the Zullinger Formation offer possibilities for an attractive monument stone or building stone. From observations in quarries the marbleoid limestones of the Rockdale Run Formation maintain these colors at depths and where free of chert nodules are in sufficiently thick beds so that large pieces could be quarried. Local shale intercalations at this horizon, however, might be a problem in quarrying.

Shales and Clay

Recent work by O'Neill and others (1965) has indicated potential utility of certain shales in Franklin County. This has led to an intensive investigation of properties and uses of shales by Karl Hoover and others of the Pennsylvania Geological Survey staff. Because of the important economic aspect of some shales, their findings are summarized in this report, but detailed information will be published at a later date.

On the basis of slow firing tests physical properties such as workability, plasticity, pH and soluble salt determinations, water of plasticity, drying and firing shrinkage, color (fired and unfired), percent cracking, apparent specific gravity, and hardness determine whether a clay is suitable for ceramic or nonceramic uses. Included under the ceramic category are clays used for whiteware, structural products, refractory products, artware or pottery, and lightweight aggregate. Included under the nonceramic category are clays used as filler for paint, plastics, paper, rubber, and clays used in oil clarifiers, abrasives, foundry molds, drill muds, and pigments (O'Neill and others, 1965).

In the area mapped the shales of the Martinsburg Formation have economic potential in ceramic use. Eleven samples of shale from the Martinsburg were collected throughout the area. Initial samples weighed 5 pounds and were tested by slow firing and then by quick firing. Those quick-fired samples that showed good bloatability, which is indicative of lightweight aggregate potential, were recollected as 200 pound specimens. These larger samples were tested by the rotary kiln method to evaluate their use in lightweight aggregate. Results of the various tests are shown in Table 5. Chemical analyses of some of the shales are shown in Table 6. Location of all samples are listed in Table 5.

Results of these tests indicate that certain shales in the Martinsburg Formation have an excellent potential as lightweight aggregate. Some may also be used as face brick and floor tile. Undoubtedly other areas in the terrane of the Martinsburg Formation contain shales suitable for lightweight aggregate and other ceramic products. Any areas that are to be developed should be thoroughly sampled and analysed prior to exploitation.

Ground Water

In the early 1960's because of drought conditions and the general increased demand of water for both industrial and domestic purposes ground water has been of considerable importance in Franklin County. It has not been within the scope of this study to examine the groundwater resources of the county but because of its importance an attempt will be made to point out some geologic features related to ground-water accumulation.

Table 5.—*Test results of shales in the Martinsburg Formation.*

Sample	*Location*	*Potential uses*
1	In NE Williamson 8900′S of 39° 52′ 30″ lat. 1700′W of 77° 47′ 30″ long.	None (narrow firing range; short working properties, negative preliminary bloating tests)
2	At Stone Bridge 7800′S of 39° 52′ 30″ lat. 2300′W of 77° 45′ long.	None (poor firing color, short working qualities, preliminary bloating test was positive but did not merit rotary kiln tests)
3	At Stone Bridge 7500′S of 39° 52′ 30″ lat. 2500′W of 77° 45′ long.	None (poor firing color, negative bloating test)
4	About 2.5 miles SE of Williamson 1400′S of 39° 50′ lat. 3900′W of 77° 45′ long.	Lightweight aggregate (best potential)
5	About 1.5 miles E of Upton 3350′N of 39° 47′ 30″ lat. 7700 W of 77° 45′ long.	Building brick (poor color, should fire to grade MW face brick at about 1950° F.)
6	In SW Greencastle 1000′S of 39° 47′ 30″ lat. 4600′E of 77° 45′ long.	Lightweight aggregate (fair potential, good pore structure, satisfactory crushing characteristics, short firing range undesirable fragment shape)
7	About 1 mile W of Greencastle 700′N of 39° 47′ 30″ lat. 300′E of 77° 45′ long.	Lightweight aggregate (fair to good potential, good pore structure, satisfactory crushing characteristics, undesirable fragment shape)
8	About 1.5 miles NW of Greencastle 7500′N of 39° 47′ 30″ lat. 2300′E of 77° 45′ long.	Face brick, floor tile
9	About 2 miles WNW of Kauffman 3000′N of 39° 50′ lat. 2700′E of 77° 45′ long.	Lightweight aggregate (fair potential, good pore structure, undesirable fragment shape, poor crushing character)
10	About 1.3 miles NW of Marion 2500′S of 39° 52′ 30″ lat. 2500′W of 77° 42′ 30″ long.	Lightweight aggregate (good potential)
11	About 0.8 miles NW of Marion 4500′S of 39° 52′ 30″ lat. 300′E of 77° 42′ 30″ long.	Lightweight aggregate (fair potential, fair pore structure, excessive loss in crushing of raw materials)

A brief study of the water resources of Franklin County was made by Hall (1934, p. 171-177). His ratings of the water-bearing properties of various formations is shown in Table 7. A quantitative study of the Cambro-Ordovician carbonates and the Martinsburg Formation was made near Martinsburg, West Virginia, by Beiber (1961) whose results (Table 8) are somewhat at variance with those of Hall (1934) in that the Beekmantown Group is rated as an excellent aquifer, the Elbrook

Table 6.—*Chemical analyses of shales in the Martinsburg Formation.*

SAMPLE#	10	6	7
SiO_2	69.00	64.10	66.00
Al_2O_3	11.60	14.00	12.00
Fe_2O_3	6.37	3.34	3.99
FeO	1.07	4.09	3.47
CaO	0.32	1.95	1.99
MgO	1.58	1.46	1.39
K_2O	3.00	3.30	3.20
Na_2O	0.95	1.58	1.65
TiO_2	0.80	0.83	0.85
L.O.I.	5.24	5.22	5.44
S	0.044	0.97	0.75
CO_2	0.37	1.54	1.36
Combined H_2O	—	—	—
110° C H_2O	0.51	0.12	0.16
C	0.35	0.43	0.54
TOTAL	101.20	102.93	102.79

Table 7.—*Water-bearing properties of various geologic units in southeastern Franklin County. After Hall (1934).*

Geologic Name	*Water-Bearing Properties*
Martinsburg Formation	Small quantities of hard water at moderate depth.
Chambersburg Formation	Fair amounts of hard water.
St. Paul Group	Some larger springs and excellent wells. Hard water.
Beekmantown Group	Solid limestone yields little water but local solution channels yield large quantities hard water.
Conococheague Group	Not a good water horizon but wells encountering solution channels yield large quantities hard water.
Elbrook Formation	Poor water horizon. Hard water.
Waynesboro Formation	Poor water horizon. Hard water.
Tomstown Formation	Wells in solid limestone are dry but wells in solution channels yield large quantities hard water. Considerable ground water at contact with underlying Antietam Formation.
Antietam Formation	Fairly good water-bearing formation. Soft water.
Harpers and Weverton Formation	Fair to poor amounts, soft water.
Metabasalt, Metarhyolite	Poor water horizon but with small springs soft water.

Table 8.—*Yield and specific capacity of Cambro-Ordovician aquifers in Berkeley and Jefferson Counties, West Virginia. Data from Beiber (1961).*

	General Well Data		*Drawdown Test*		
GEOLOGIC UNIT	AVERAGE YIELD (g.p.m.)	NO. WELLS	MEDIAN YIELD (g.p.m.)	MEDIAN SPECIFIC CAPACITY g.p.m./ft. DRAWDOWN	NO. WELLS
Martinsburg	21	35	21	8	8
Chambersburg	18	11	18	5.1	3
Saint Paul	16	3			
Beekmantown	69	55	200	5	7
Conococheague	16	24	14	.5	7
Elbrook	26	12	17	2.2	5
Waynesboro	26	9	20	4	3

is rated as good, the Martinsburg is rated as fair, and the Chambersburg, St. Paul, and Conococheague Formations are rated as poor. It is felt that the small number of wells used in evaluation of the St. Paul do not accurately reflect the aquifer potential of this unit.

In drilling for water in bedrock the writer would ascertain that zones of pure limestone and zones of faulting might yield more water than impure limestones or areas of structural homogeneity. The pure limestones are more soluble and hence tend to contain more caverns and solution channels. Zones of faulting would tend to have more fractures than unfaulted areas. The St. Paul Group, marbleoid limestones at the base of the Rockdale Run Formation, and Zullinger Formation might be more prospective aquifers than adjacent less pure limestones. Proximity of wells to major faults as shown on the geologic map (Plate 1) might also yield more water.

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APPENDIX

MEASURED SECTIONS

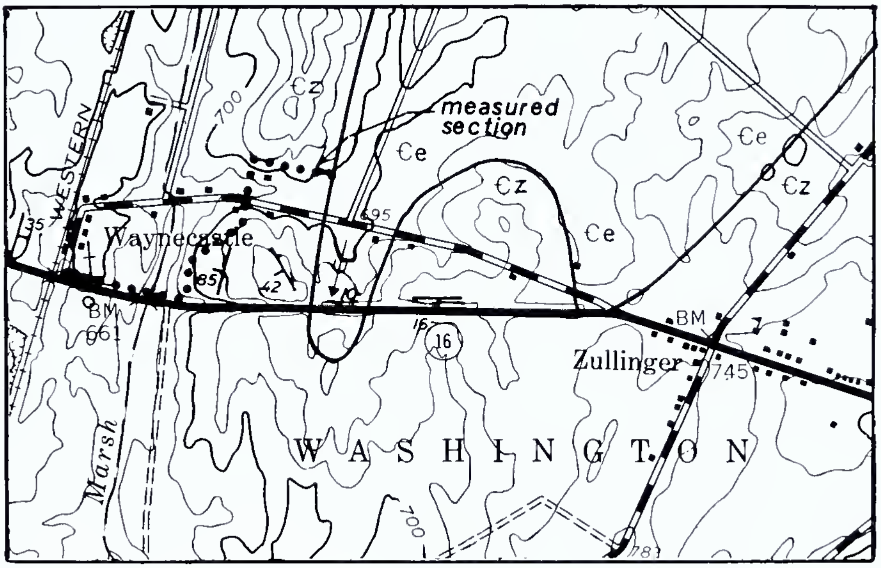
LOCALITY 1—ZULLINGER SECTION

This section is designated as the type section of the Zullinger Formation of the Conococheague Group. Only the middle and lower portions, some 2,100 feet thick, are exposed.

The base of the section is located 8,000 feet north of latitude 39° 45′ and 5,000 feet west of longitude 77° 37′ 30″. From here the section passes southwest through pastures, crosses country road 28062, passes through more pasture and then onto State Highway 16. From here, westward, it follows the exposures in the road cuts along the highway. The section terminates at the entrance to Waynecastle Dairy at the overpass of the Western Maryland Railroad.

West of the railroad the Zullinger beds pass into a synclinal fold which omits the youngest beds. The contact with the Elbrook at the base of the section is not exposed. It is selected on the break in topography, termination of outcrop, and proximity of Elbrook rocks in the core of the anticline east of the contact Conococheague Group.

Zullinger Formation (2,100 feet, partial section—uppermost part not present).



Unit		*Thickness (In feet)*
1	Limestone, N4, weathers N7 to N8, finely crystalline with flecks of clear spar 1 to 2 mm across that probably are fossil fragments, with sandy dolomitic partings hairline to 4 mm thick.	4
2	Limestone, N5, weathers N4, very finely crystalline to finely crystalline, in laminae to 2 inches thick, with interlaminae of slightly sandy dolomite 10YR8/6 to 10YR8/2.	11
3	Covered interval.	10
4	Limestone similar to Unit 1.	28
5	Dolomite, buff, slightly limy, silty, very finely laminated on weathered surface.	3
6	Covered interval.	8
7	Limestone, finely crystalline, interlaminated to interbedded with dolomite stringers, a few thin beds are silty and argillaceous. This exposure is overgrown with vegetation.	50
8	Interlaminated limestone and dolomite in equal amounts. Limestone is blue-gray and very finely crystalline, dolomite is buff and silty. Beds are ¼ to ½ inch thick and vary from planar to undulating, with traces of intraformational conglomerate.	1.5
9	Limestone, N6 and N7, weathers N6 to N7, very uniform, massive with slightly waxy luster, very finely crystalline to aphanitic, with hairline dolomitic partings that are semi-stylolitic in appearance.	4.3
10	Limestone as above but with a few dolomite laminae to 1 inch thick, in part forming an intraformational conglomerate.	2.2
11	Limestone, very finely laminated, laminations are from hairline thickness in most cases to ¼ inch thick, they are very planar but in a few places show small-scale cross-bedding on the order of 2- to 3-inch foreset beds, also these grade into small intraformational conglomerates. Laminations are due to either buff silty dolomite laminae or silty laminae with the grain size difference. This grades into finely laminated dolomite below over a 3 inch interval.	1.7
12	Dolomite, N3, weathers 5Y6/1, very finely crystalline, slightly silty, very finely planar laminated throughout, limier at base and top, grades into underlying unit.	2.5
13	Limestone, blue-gray, weathers buff, composed of fine planar laminae ⅛ to ¼ inch thick, but many hairline thick laminae, quite silty.	3
14	Limestone, similar to Unit 11.	4
15	Limestone, N3, weathers N5, very finely crystalline, homogeneous in most part, but with abundant hairline to ⅛-inch thick laminae of more dolomitic limestone. These laminae are spaced from ⅛ to 3 inches apart, laminae undulating to moderately wavy.	4.7
16	Limestone and limy dolomite, interbedded and interlaminated, limestone 70 percent, limy dolomite 30 percent, limestone weathers N5, limy dolomite 10YR7/4, the color is variable, the dolomite is very finely crystalline as is the limestone. Limestone in beds ½ to 1 inch thick, dolomite in beds ¼ inch thick with abundant lichen growing on it and not on the limestone. No laminae are planar, all are wavy giving a ripple-marked appearance in places, in other places laminae have pulled apart forming boudinage (not tectonic). There are three intraformational conglomerate beds, maximum 6-inches thick, in this unit. This is a distinctive lithology of the Conococheague Group.	5.9

Unit		*Thickness (In feet)*
17	Limy dolomite, buff color, very hard and compact, very finely granular and silty, slightly laminated, with a local intraformational conglomerate at the top.	0.5
18	Interlaminated limestone and limy dolomite similar to Unit 16. Limestone 65 percent and limy dolomite 35 percent of unit, the dolomite laminae are thicker than in Unit 16 but many ½ to 1 inch thick, towards base a couple of 2- to 3-inch intraformational conglomerate beds.	6.5
19	Mechanical limestone, N3, weathers N5 to N6, colors are slightly variable, consists of very finely crystalline matrix with floating very fine to fine sand-size grains of clastic limestone material probably organic in part. The clastic portion is darker than the matrix but is probably spar material, some ½- to 1-inch irregular patches of calcite spar and a few semi-planar ⅛- to ¼-inch limy, buff dolomite laminae. At base is a 2-inch intraformational conglomerate.	1.5
20	Interlaminated limestone and limy dolomite similar to Unit 18.	5.9
21	Mechanical limestone similar to Unit 19. Unit 20 rests on this unit with a disconformity, undulating surface has ¾-inch deep channels. A few hairline dolomite laminae are present.	1.2
22	Algal-mechanical limestone, with stromatolites up to 3 feet wide at base and 1½ feet high, with abundant laminae to 2 inches thick of buff limy dolomite, these are irregular in character and truncated by the stromatolites.	4
23	Interlaminated limestone and dolomite. Limestone 65 percent and dolomite 35 percent of unit. Limestone in bands ½ to 1 inch thick, dolomite in ⅛- to ¼-inch thick bands. Many of the limestone beds are mechanical, fine calcarenites with varying clastic contents ranging from good calcarenites to floating sand grains. A few beds are just very finely crystalline limestone with no clastic component. Disconformable on lower bed, channeled into it in 2-inch deep channels. Dolomite is semi-planar with some beds undulating to ripple-marked appearance.	6.5
24	Limestone, N4 to N5, weathers N8, homogeneous at top, very finely crystalline, with scattered fine calcite sand grains, amount increasing to base where there is almost a mechanical limestone, basal 1 foot is in part intraformational conglomerate and in part looks oolitic. It is suspected that there are some stromatolites here but they do not have an obvious appearance. With a few discontinuous small patches of dolomite and dolomite laminae.	2.1
25	Limestone, N4 to N5, weathers N8 very finely crystalline, silty, with traces of clastic grains, mottled throughout with buff silty dolomite.	4.1
26	Dolomite and limestone, finely interlaminated, dolomite 70 percent, limestone 30 percent, planar lamination on hairline scale to ¼-inch bands, contains more limestone at base and top and almost pure dolomite at center.	2.9
27	Interlaminated limestone and dolomite similar to Unit 23, with several 5-inch thick intraformational conglomerate beds, limestone shows cross-bedding laminae and is silty.	27.1

Unit		*Thickness (In feet)*
28	Limestone, N3, weathers N6, homogeneous mechanical calcarenite probably bioclastic but grains rounded, some hairline thick dolomite laminae.	3.9
29	Limestone, calcarenite to intraformational conglomerate, maximum conglomerate clasts are ½ inch by 3 inches.	0.9
30	Limestone, and interlaminated dolomite similar to Unit 23.	21.9
31	Limestone, oolitic intraformational conglomerate, with clasts to 2 inches.	6.9
32	Limestone and interlaminated dolomite similar to Unit 23 but very little mechanical limestone except in basal 6 inches.	3
33	Limestone, N5 to N6, weathers N6, mechanical with abundant oolites and floating well-rounded quartz grains, high porosity, medium- to coarse-grained, with a very few thin dolomite laminae, quite arenaceous at base.	2.5
34	Limy sandstone, fine- to medium-grained but with a few 1-inch thick beds of coarse quartz grains, all well-rounded and highly spherical, shows small-scale deltaic cross-bedding with foreset sweeps to 4 inches, current probably from north and west, individual beds 2 inches, sand content variable from sandstone to sandy limestone, some oolites present.	1.7
35	Very limy sandstone to sandy limestone, becoming more arenaceous to base, intraformational conglomerate throughout composed of rounded limestone clasts to 2 inches. Sandstone is medium- to coarse-grained, well-rounded and highly spherical, nearly all grains are light-gray transparent.	1.1
36	Sandy dolomite, upper two-thirds is intraformational conglomerate with clasts to 3 inches, lower part laminated, with beds of quartz sand as above and zones of very sandy dolomite. Lowermost 6 inches laminated and free of quartz sand.	2.5
37	Limestone, light-gray, very finely crystalline, with fine semi-planar laminations of dolomite, hairline to ⅛ inch thick.	6.3
38	Limestone similar to Unit 23 but no mechanical limestone.	3.5
39	Limestone, light-gray, weathers N6 to N7, bioclastic with abundant brachiopod-valve fragments, with several stylolitic dolomite laminae.	0.5
40	Limestone, colored as above but many laminations of dolomite. Dolomite is hairline to 1/16 inch in thickness and the limestone is in laminae ¼ inch to 1 inch thick. Laminae are mostly wavy and some even semi-stylolitic but a few are perfectly planar. Limestone is silty, very finely crystalline with one 3-inch bed of bioclastic limestone noted 4 feet above top. Small streaks and lenses of bioclastic material floating in micrite matrix throughout.	9.6
41	Interlaminated dolomite and limestone, the buff, limy dolomite is 60 percent and the blue-gray limestone, 40 percent of unit. In middle of unit dolomite increases to 80 percent. Laminations are hairline to ⅛ inch thick and interlaminated on the same scale, laminations are semi-planar.	4.7
42	Interlaminated limestone and limy dolomite, similar to Unit 38.	2.5
43	Oolitic, calcarenitic, and bioclastic limestone, N5 to N4, weathers N6, oolitic at top, clasts are well-rounded and spherical, none exceeds coarse sand-grain size.	0.7

Unit		*Thickness (In feet)*
44	Limestone intraformational conglomerate, color as above, clasts less than 1 inch, in very finely crystalline matrix, some oolitic, calcarenitic and bioclastic components. Top and bottom contact sharp, top cut into by overlying units and beds cut out.	3
45	Limestone similar to Unit 43.	0.5
46	Oolitic intraformational conglomerate similar to Unit 44, matrix primarily oolite, clasts average 1 inch.	0.8
47	Oolitic limestone.	0.3
48	Oolitic intraformational conglomerate.	0.3
49	Interlaminated silty dolomite and limestone.	0.1
50	Limestone intraformational conglomerate, color similar to previous, clasts to 1½ inches, matrix fine-grained calcarenitic, with trace of bioclastics in micrite.	1.1
51	Finely interlaminated limestone and dolomite. Limestone 60 percent, dolomite 40 percent, laminae average ⅛ to 1/16 inch thick and interlaminated on the same scale, semi-planar in most part, with a few 2-inch beds of calcarenite and single bed of intraformational conglomerate, dolomite content increases to base.	4.5
52	Mechanical limestone, calcarenitic, oolitic, bioclastic, in fine-medium sand-grain size, with some very fine laminae of silt and dolomite, has base of 2-inch thick intraformational conglomerate.	5.7
53	Interlaminated limestone and dolomite similar to Unit 51 but maximum dolomite development is 2 feet below top.	6.0
54	Oolitic limestone, well-sorted, average medium-grained sand size, with minor calcarenitic and bioclastic admixture.	2
55	Mechanical limestone, N3 to N4 weathers N5, fine- to medium-grain size calcarenitic, with fine to coarse grains of bioclastic detritus, all very finely cross-bedded, silty ?, cross-bedding on scale of several inches, seems to be torrential type.	5.9
56	Mechanical limestone as above but with some 2-inch thick yellowish-orange dolomite bands.	2.1
57	Mechanical limestone similar to Unit 55 but with welded stylolites and a few 1-inch thick dolomite beds, in lower portions cross-laminations give way to semi-planar laminations.	5.8
58	Mechanical limestone, intraformational conglomerate with matrix of calcarenite.	0.5
59	Limestone, colors as previous, very finely crystalline, massive.	0.5
60	Limestone similar to Unit 50.	0.2
61	Limestone similar to Unit 59.	0.2
62	Bioclastic limestone, coarse-grained to very coarse-grained size with traces of oolites and intraformational conglomerates.	0.5
63	Mixed bioclastic and calcarenitic limestone, medium-grained size.	0.3
64	Limestone, intraformational conglomerate, average clasts are ½ inch, with calcarenitic fine-grained matrix.	0.3
65	Interlaminated limestone and dolomite, on scale hairline to 1/16 inch thick. Dolomite increases towards base, laminae are semi-planar.	5.9
66	Limestone, N3, weathers N6, very finely crystalline, very finely laminated, silty, with some dolomite laminae.	2.8

Unit		*Thickness (In feet)*
67	Mechanical limestone, uppermost 2 inches is intraformational conglomerate then 3 inches of oolitic limestone, the remainder is fine- to medium-grained calcarenitic material, with 3 inches intraformational conglomerate at base.	2.5
68	Dolomite, yellow-orange 10YR, with fine semi-planar interlaminations of limestone.	1.0
69	Interlaminated limestone and dolomite in equal amounts, laminae are planar and on hairline scale, middle of unit is very dolomitic.	13.5
70	Limestone, N3 to N4 weathers N7, very finely crystalline to aphanitic in most part, there are a few very fine-grained to fine-grained calcarenitic beds. In beds ¼ to 4 inches thick with dolomite laminae hairline to ¼ inch forming 25 percent of the unit, laminae wavy to contorted.	16.5
71	Limestone and dolomite very finely laminated on hairline to 1/16-inch scale. Limestone 65 percent, dolomite 35 percent of unit.	3
72	Covered interval.	52
73	Arenaceous mechanical limestone, blue-gray, intraformational conglomerate with clasts to ½ inch, matrix with abundant floating, coarse quartz-sand grains that are well-rounded and spherical, some oolitic and calcarenitic components, quartz grains are light gray and transparent, also some appear frosted on weathered surface but this may be result of weathering.	0.3
74	Arenaceous limy dolomite to dolomitic limestone, N3 to N4, weathers in range of 10YR, with abundant floating, medium to coarse grains of quartz sand that are well-rounded and highly spherical.	1.7
75	Interlaminated limestone and dolomite, very finely interlaminated on hairline scale. Laminae are planar to semi-planar. 60 percent limestone, 40 percent dolomite, shows graded bedding.	3.5
76	Limestone, interlaminated with dolomite on a coarse scale. Limestone in laminae and bands ¼ to 3 inches thick. Dolomite ⅛ to ½ inch thick. Limestone is silty and quartzose in part, mostly very finely crystalline but with very little calcarenite and some algal beds to 3 inches thick, some intraformational conglomerate. Limestone is N3 to N4, weathers N6; dolomite is 10YR6/2, weathers 5Y5/2.	8
77	Limestone and dolomite similar to Unit 75.	8.8
78	Limestone similar to Unit 76 but limestone is all very finely crystalline to microcrystalline.	4.2
79	Limestone, mechanical calcarenitic to intraformational conglomerate within individual beds, with a few thin dolomite laminae.	0.9
80	Limestone, intraformational conglomerate, with clasts to 3 inches, with many strongly developed welded stylolites cutting through clasts, all set in a very fine to fine silty calcarenitic matrix.	2.5
81	Similar to Unit 76, but with some fine calcarenitic to intraformational conglomerate interbeds.	18.6
82	Oolitic limestone, medium-grained, with subordinate amounts of medium- to coarse-grained bioclastic grains, and medium- to coarse-grained clastic detritus. Unit is homogeneous, with a very few welded stylolitic and dolomitic laminae.	5.2
83	Covered interval. Assumed to be oolitic limestone.	2

Unit		*Thickness (In feet)*
84	Algal limestones with algal heads 1 foot high and 2 feet across at the base, with a 6-inch layer of oolitic limestone at the top.	1.5
85	Interlaminated limestone and dolomite with dolomite decreasing in amount downward, 1½ feet below top is an 8-inch dolomite bed.	11.9
86	Intraformational limestone conglomerate, with clasts ½ to 1 inch thick, near the base is an 8-inch thick pocket of coarse-grained oolitic limestone.	4.5
Note:	From here traverse leaves State Highway 16 and enters field to north.	
87	Limestone and dolomite, finely interlaminated in upper half then a 1-foot dolomite bed and below this banded limestone and dolomite.	7
88	Limestone, medium-gray, fine-grained, calcarenitic, well-sorted, with a 2-inch intraformational conglomerate at the top, contact with Unit 87 gradational but in places slightly channeled.	2.5
89	Limestone, finely laminated to slightly banded.	0.5
90	Covered interval.	7.7
91	Limestone and dolomite, interbanded on the scale ½ to 3 inches, limestone and dolomite in equal amounts, maximum development dolomite in center of unit and forming thickest bands, above and below this, bands average 1 inch thick and limestone is predominant. The limestone is N3 to N4, weathers N6 to N7, and is very finely crystalline to microcrystalline, the banding is wavy to boudinage in structural appearance. The dolomite is overgrown with lichen and difficult to determine color but similar to Unit 87.	3.6
92	Covered interval.	17
93	Similar to Unit 91 but with several 1- to 3-inch bands of intraformational conglomerate, clasts are all rounded with maximum length to 2 inches, matrix is more dolomitic and silty and is a very fine calcarenite. Limestone 75 percent, dolomite 25 percent, with maximum concentration and thickness of dolomite in middle of unit.	10
94	Covered interval.	74
95	Limestone, light- to medium-gray N5 to N7, very fine-grained calcarenite, laminated, with a few irregular dolomite bands at the top and bottom. In middle are some isolated light-brown, very hard and granular cherts that form irregular patches 10 × 5 × 2 inches.	4.9
96	Interbanded limestone and dolomite, in approximately equal amounts, in bands ½ to 2 inches thick, with slightly wavy structure.	4.5
97	Limestone, light-gray, N8, very fine-grained calcarenite, with faintly mottled structure and a very few dolomite bands.	1.6
98	Covered interval.	3.3
99	Dolomite, 10YR, with much lichen covering outcrop, homogeneous, slightly laminated.	2
100	Covered interval.	260
101	Interbanded limestone and dolomite, limestone N4 weathers N6, microcrystalline, average band 1 inch thick, average dolomite band ¼ to ½ inch thick. Bands are wavy and form boudins in places. Dolomite is 10YR and comprises 30 percent of the unit.	34.6
Note:	From here the traverse diverges from that of Wilson. Traverse proceeds northeast through the pastures to core of the anticline, because of greater amount of outcrop.	

Unit		*Thickness (In feet)*
102	Covered interval.	11.5
103	Limestone interbedded with dolomite, very finely crystalline to microgranular.	5.5
104	Covered interval.	8.5
105	Similar to Unit 103.	3.3
106	Covered interval.	4.9
107	Limestone, N4, weathers N6, very finely crystalline to very fine-grained calcarenite, laminated to cross-laminated in part, with 30 percent partings and bands of 10YR dolomite. A few 2-inch intraformational limestone conglomerate bands present; the limestone has abundant dolomite silt throughout and traces of quartz silt.	21.6
108	Mechanical limestone, weathers similar to Unit 107, very fine-grained calcarenite, with sparse layers floating very fine bioclastic material, several dolomitic stylolites, traces thin local intraformational conglomerate.	3
109	Limestone and dolomite, finely interlaminated. Poorly exposed.	5.5
110	Sandstone, medium-grained at base, grading into fine- to medium-grained at top, very well-sorted, highly spherical, very well-rounded, frosted to slightly vitreous luster, with calcareous to dolomitic calcareous cement. Contact with underlying unit shows as much as 6 inches local relief, appears to be erosional contact.	1.8
111	Dolomite, N6, weathers 10YR8/6 to 10YR7/4, very finely crystalline throughout, very hard, finely laminated on weathered surface, in middle is a ½ inch thick variegated shale.	2.5
112	Limestone and dolomite, interbanded, limestone 65 percent and dolomite 35 percent. Limestone medium-gray, very finely crystalline to slightly granular, and laminated within individual limestone bands. Banding is wavy.	14.5
113	Limestone intraformational conglomerate, with clasts to 5 inches, average 1 to 2 inches, increasing in size at base, well-rounded. Matrix medium-grained calcarenite to bioclastic by fragmentation of layers of Unit 114.	1.2
114	Mechanical limestone, fine-grained calcarenitic, with some fine-grained, clear grains of bioclastic material.	1.3
115	Limestone and dolomite similar to Unit 112, with a few intraformational conglomerate streaks.	18.8
116	Limestone, N3 to N4, weathers N5 to N6, very finely crystalline, with a few irregular and discontinuous dolomite laminae.	1.8
117	Dolomite, similar to Unit 111.	0.9
118	Limestone and dolomite, similar to Unit 115.	24.1
119	Limestone and dolomite interlaminated on a hairline scale, planar laminae grading down into dolomite by decrease in amount of limestone interbeds.	1.1
120	Dolomite similar to Unit 111.	3.5
121	Interbanded limestone and dolomite, with blebs of granular gray chert, similar to Unit 115.	3.1
122	Mechanical limestone, grades from intraformational conglomerate at base to laminated, very fine-grained calcarenite at top, in part indistinctly algal at top of intraformational conglomerate, with a few dolomite partings, this sharply truncates underlying units.	3.9

Unit		*Thickness (In feet)*
123	Dolomite, similar to Unit 111, in upper few inches finely laminated with limestone.	1
124	Limestone and dolomite, interbanded, very poorly exposed.	12.4
125	Limestone and dolomite, similar to Unit 112.	12
126	Intraformational limestone conglomerate, clasts very thin but 2 to 3 inches long, grades into very fine-grained calcarenite at top, the crystallization makes it difficult to distinguish between very fine-grained calcarenite and calcisiltite and very finely crystalline to microcrystalline limestone.	4
127	Covered interval.	1.1
128	Limestone and dolomite, similar to Unit 112.	3.4
129	Limestone, intraformational conglomerate, clasts ½ to 1 inch in length.	2.1
130	Limestone and dolomite, interbanded, similar to Unit 112.	1.7
131	Covered interval.	5.9
132	Dolomite, similar to Unit 111.	1.5
133	Covered interval.	7.8
134	Mechanical limestone, mostly very fine-grained calcarenite to, in part, very finely crystalline; with some beds 5 inches thick of intraformational conglomerate and bands of fine- to medium-grained bioclastic detritus, with several zones of dolomite banding.	13.4
135	Slightly limy dolomite, similar to Unit 111, weathered surface yellowish-gray, 5Y7/2.	6.6
136	Limestone and dolomite interbanded, similar to Unit 112.	3.9
137	Mechanical-algal limestone, medium-grained calcarenite—bioclastic limestone, with several indistinct algal heads *in situ* and draping of beds over these heads.	2.8
138	Limestone, very finely laminated, in beds 1 inch thick, with dolomite laminae separating these beds, bedding and laminae are highly undulose in character, amplitude increasing upwards, upper beds could be algal incrustation.	1.8
139	Limestone and dolomite, laminated, amount of dolomite increases to center of unit forming a nearly pure 8-inch thick dolomite bed.	2.6
140	Limestone, mechanical, very fine-grained.	1.6
141	Limestone and dolomite, interlaminated, with some limestone in bands 2 inches thick, internally showing laminae, cross-laminae and convolute bedding.	2.8
142	Dolomite, similar to Unit 111.	2.7
143	Dolomite, very finely interlaminated with limestone.	1.1
144	Limestone and dolomite, banded.	2.1
145	Mechanical limestone, fine-grained calcarenitic, well-sorted, homogeneous.	3
146	Limestone and dolomite, very finely laminated, concentration of dolomite in upper part.	4.5
147	Limestone and dolomite, interbanded, 70 percent limestone, and 30 percent dolomite, dolomite bands ¼ to ½ inch thick, limestone bands ½ to 1 inch thick, banding is semi-planar.	7.3
148	Limestone and dolomite, very finely laminated.	3.5

Unit		*Thickness (In feet)*
149	Limestone and dolomite, interbanded, with a single 3-inch thick intraformational conglomerate band.	9.4
150	Limestone and dolomite interlaminated on a hairline scale.	9.5
151	Interbanded limestone and dolomite, limestone bands are laminated and interlaminated with dolomite.	6.3
152	Mechanical limestone, mostly fine-grained calcarenite. Poorly exposed.	14.3
153	Interbanded limestone and dolomite, with a few thin intraformational conglomerate beds, and also a few beds to 1½ feet thick of very finely crystalline to microcrystalline pure limestone.	26.3
154	Interlaminated limestone and dolomite.	8.9
155	Interbanded limestone and dolomite.	12.1
156	Mechanical limestone, very fine-grained calcarenite to very fine crystalline limestone, with layers of fine- to coarse-grained bioclastic detritus, no intraformational conglomerates present, there are many algal colonies present but they are indistinct in development.	8.4
157	Interbanded limestone and dolomite, limestone is N4 weathers N6, very finely crystalline to microcrystalline in most part, in a few places laminated with very fine-grained calcarenitic texture, with several thin intraformational conglomerate beds. Dolomite weathers 5Y6/4.	31.7
Note:	From here near fence line at road move 300 meters north along strike across road (Legislative Route number 28062) and into field. Continue section from here.	
158	Intraformational limestone conglomerate, clasts to 1½ inches but mostly matrix material, medium-grained bioclastic and calcarenite grains and some oolites in cement. In center a few dolomite bands. Conglomerates developed at top and bottom of unit.	2.5
159	Interlaminated limestone and dolomite, varvelike appearance, even the laminations appear cyclical in that there is an abundance of dolomite at base of unit decreasing in amount upward.	11.1
160	Limestone, interbedded with chert and cherty dolomite, limestone is very finely crystalline at base grading to medium-grained bioclastic with intraformational conglomerate beds at top, near top are irregular small masses of granular chert that are crustlike in character, these bands become silty and cherty dolomite toward base.	7.9
161	Interbanded limestone and dolomite, with amount of dolomite increasing to base and at base a 1-foot bed of 70 percent dolomite. Basal beds in knife-edge contact with underlying unit.	8.6
162	Mechanical limestone, medium-grained calcarenite with medium to coarse grains of bioclastic material, with a few thin beds of fine intraformational conglomerate, with rolling erosional contact on Unit 163.	3.1
163	Interbanded limestone and dolomite. Limestone is very fine-grained calcarenite to calcisiltite or very finely crystalline to microcrystalline, it is silty. The dolomite bands are very cherty and weather with chertlike relief but are leached and light in weight.	17.6
164	Dolomite, 10YR, massive, homogeneous, silty. Not well exposed.	2.4
165	Covered interval.	5.4
166	Algal limestone, of the encrusting type, in beds ½ to 1 inch thick, with dolomite partings. This unit is entirely algal. It contains a few blebs of yellow-gray granular chert.	5.1
167	Covered interval.	21.5

Unit		*Thickness (In feet)*
168	Interbanded limestone and dolomite, limestone is very fine to fine calcarenite with some bands of very finely crystalline to microcrystalline limestone. With 20 percent bands and irregular mottlings of dolomite. In a few places, at base, algae of pipe-type form.	3.1
169	Dolomite, yellow-brown, massive, hard, homogeneous, slightly laminated on weathered surface. Poorly exposed.	1.7
170	Covered interval.	1
171	Algal limestone, of the cabbage-head type.	1.1
172	Oolitic limestone, with some intraformational conglomerate horizons, oolites are size of medium sand grains, well-sorted; at top is a bed 1 to 3 inches thick of chert which has silicified the oolites, a few small chert blebs and nodules are present in middle of unit.	2.6
173	Algal-mechanical limestone, at base an intraformational conglomerate, and indistinct colonies, which passes laterally in 15 feet into a purer fine- to medium-grained calcarenite and minor intraformational conglomerate. The oolites of Unit 172 fill depressions on the cabbage-head algae.	1.1
174	Interbanded limestone and dolomite.	0.5
175	Covered interval.	3.9
176	Algal limestone, N5 to N6, weathers N7 to N8, on fresh surface, shows some fine to medium crystallinity and patchy appearance, on weathered surface has a blotchy fine marbleoid appearance, algal structure indistinct, marked by hairline dolomite partings and extremely intricate stylolitic pattern in the interior of algae, the heads or upper surface are marked by thicker arched dolomite partings. These seem to be pipelike algae growing side-by-side.	8.6
177	Covered interval.	2.2
178	Mechanical limestone, mostly very fine-grained calcarenite but with some fine to medium bioclastic admixture, some indistinct algal beds, a few argillaceous dolomite partings.	7
179	Oolitic limestone, medium sand-size, well-sorted, in places some intraformational conglomerate clasts.	3.6
180	Interbanded limestone and dolomite, grades laterally along strike to pure dolomite.	1.9
181	Covered interval.	1.3
182	Limestone, calcarenite, cross-laminated showing current moving to south, medium-grained, well-sorted.	2
183	Interbanded limestone and dolomite, in part banding grades to mottling.	3.5
184	Algal limestone, similar to Unit 174.	2.9
185	Covered interval.	5.6
186	Limestone, mostly very finely crystalline to microcrystalline with a few streaks of very calcarenitic admixture. Subordinate dolomite bands present, undulating to wavy.	10.5
187	Covered interval. Float blocks in interval are mostly mechanical-algal limestone type.	27
188	Interbanded limestone and dolomite, some of the dolomite is 1 foot thick but pinches and swells abruptly, this is due to infilling on surface of underlying algal limestone. The dolomite appears to be secondary.	3.1

Unit		*Thickness (In feet)*
189	Algal-mechanical limestone, the pipe type, the encrusting type, and cabbage-head type of algae are present, with streaks and lenses of calcarenitic, oolitic limestone. Sixty feet along strike is a channel of pure calcarenitic, oolitic limestone.	5
190	Poorly exposed, partially dolomitized algal-mechanical limestone, varies from pure limy dolomite to mechanical-algal limestone with dolomite mottlings in 50 feet along strike.	3.4
191	Very poorly exposed. Blocks of dolomitized mechanical-algal limestone present here.	8.9
192	Silty dolomitic mudstone, N4, weathers light olive gray, 5Y5/2, laminated to very finely banded, blocky fracture, no fissility.	1.5
193	Covered interval.	2
194	Dolomitized limestone, over a strike interval of 200 feet varies from limestone with dolomite mottlings to pure limy dolomite. Limestone is medium-gray and a very fine-grained calcarenite with suggestions of algal material. Dolomization shown by patchy distribution of dolomite crystals to dolomite patches with no apparent control. Some dolomite beds have sharp contact but climb across limestone beddings.	7.5
195	Covered interval.	5.3
196	Limestone, with subordinate dolomite bands, varies along strike from algal to mechanical-calcarenitic limestone, in places bands go to boudin structure; some secondary dolomization in lower part.	5.4
197	Poorly exposed. Similar to Unit 192.	6.7
198	Dolomitic mudstone. Similar to Unit 190.	0.3
199	Dolomite, 10YR, massive.	4.2
200	Sandstone, at base granules to very fine pebbles grading up into well-sorted, medium-grained sandstone, frosted, light-gray and transparent to translucent, highly spherical and well-rounded.	0.2
201	Covered interval.	0.2
202	Interbanded limestone and dolomite, limestone is very fine-grained to fine-grained calcarenite with small bioclastic admixture, slightly dolomitized. Dolomite bands are mostly primary.	4.2
203	Dolomite, 5YR8/1, weathers light shade of 5YR8/1. Fine-to medium-crystalline, appears primary.	2.1
204	Interbanded limestone and dolomite, partially dolomitized.	3.5
205	Intraformational limestone conglomerate, clasts are granule to very fine pebble size, partially dolomitized.	1
206	Covered interval.	180
207	Interbanded limestone and dolomite, dolomitized.	3
208	Limestone, patchy coloring obscures lithology, probably mechanical-algal limestone, with a few patches of secondary dolomite.	3.3
209	Dolomite, finely laminated.	1
210	Covered interval.	3.1
211	Limy dolomite, N5, weathers from 5Y7/2 to 10YR8/6 to 10YR7/4, very finely crystalline, well-laminated, silty at top.	10.7
212	Dolomite, limy, lighter color than Unit 209, fresh surface N6, weathers 5YR8/5 to 5Y8/2, microcrystalline, structureless.	1

Unit		*Thickness (In feet)*
213	Sandstone, medium- to light-gray, medium-grained, well-sorted, calcareous cement, fairly high spericity, fair rounding. Very sharp contact with underlying and overlying beds.	1
214	Limestone, mechanical (?).	5.3
215	Covered interval. Several 2-foot ledges of limestone poorly exposed in interval.	74.4
216	Sandstone, light- to medium-gray, medium- to coarse-grained, well-sorted, slightly limy but leached in many places.	0.2
217	Silty dolomite, buff, laminated, medium-crystalline, hard.	1.9
218	Covered interval.	3.5
219	Sandstone, similar to Unit 213.	0.5
220	Covered interval.	2.6
221	Dolomitic sandstone, light-gray to orange-brown, at base very well-sorted, coarse-grained sandstone becoming fine to medium at top and with dolomite bands. At base dolomitic cement, high sphericity and good rounding throughout.	3.3
222	Covered interval.	0.5
223	Limestone, probably algal, with a few highly contorted dolomite laminae, on weathered surface appears microcrystalline with some bioclastic and intraformational conglomerate admixture.	4.9
224	Nodular limestone, with partings red silty mudstone, limestone in beds 1 to 2 inches and partings in ¼-inch thick bands.	0.6
225	Sandstone and interbedded limestone, sandstone well-sorted, medium-grained, limestone is at base, with thin intraformational conglomeratic and sandstone bands sharp contact with overlying unit.	1.3
226	Dolomite 10YR, laminated to banded, with a few thin bands of floating, medium coarse-grained sand.	2.3
227	Covered interval.	1
228	Oolitic limestone, medium-grained, well-sorted, with a few bands of calcarenite and intraformational conglomerate. There are channels cut into the oolitic limestones and the channels are filled with interbanded micritic limestone and dolomite.	3.1
229	Interbanded limestone and dolomite.	2
230	Covered interval. Offset traverse 120 meters north along strike and resume traverse from here.	5
231	Sandstone and interbanded limestone similar to Unit 225.	16.3
232	Mechanical limestone, calcisiltite, with a few patches of very fine calcarenite.	2.3
233	Covered interval.	2.5
234	Mechanical limestone, mixture of various sizes from calcarenite to calcisiltite with some intraformational conglomerate and bioclastic admixture.	1.9
235	Interbanded limestone and dolomite, similar to Unit 225.	6.8
236	Oolitic limestone, medium- to coarse-grained, highly stylolitic.	1.9
237	Covered interval.	4.9
238	Dolomitic mudstone, N5, weathers 5Y5/2, finely laminated to finely banded with few limestone lentils. It could be an argillaceous dolomite.	1

Unit		*Thickness (In feet)*
239	Interbanded limestone and dolomite; limestone mostly calcisiltite some microcrystalline dolomite bands, typically silty and argillaceous.	3.8
240	Seventy percent exposed. Algal to mechanical limestone, the algal colonies are in most part indistinct and show as marbly splotches in the limestone, but enough good algal colonies show up to prove that algal pipes and channels are present; with some beds of fine calcarenite and bioclastic material. Near base a bed of coarse oolites 2 feet thick. A few 2- to 4-foot interbeds near top of interbanded limestone and dolomite. There are some dolomitic laminae that show the algal forms, and sparse interbands of dolomite throughout but essentially this is a pure limestone unit.	87
241	Sandy dolomite. 10YR, but in lower part with bands and laminae of fine quartz sands.	5.1
242	Fifty percent outcrop. Composed of two types of interbedded limestone. Some beds are composed of limestone and dolomite and subordinately other beds are composed of mechanical limestone probably in which some algal components are present. In beds 3 to 4 feet thick.	115

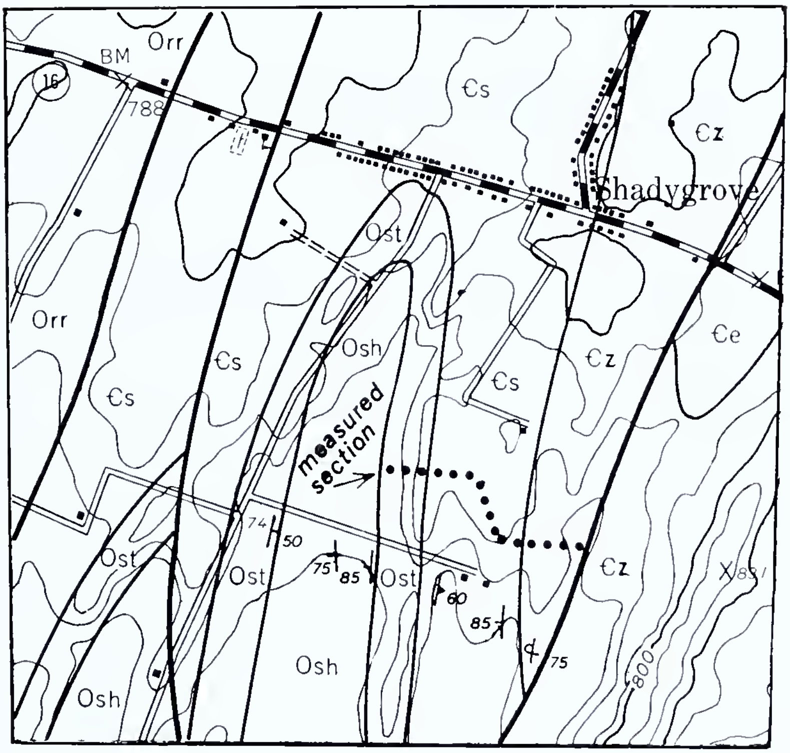
Beyond this unit there is no outcrop, and the contact with the Elbrook is selected here. There is a good topographical break here as well. In a small hill north of this station, good Elbrook limestones are exposed. It should be noted that Conococheague-type lithologies persist well into the Elbrook Formation and it is always difficult to select the contact between the two units.

LOCALITY 2—SHADYGROVE SECTION

About 3,500 feet south of Shadygrove, Pennsylvania is the type section of the newly designated Shadygrove Formation of the Conococheague Group. Included in this section is a part of the underlying Zullinger Formation of the Conococheague Group and all of the overlying Stoufferstown Formation of the Beekmantown Group.

The base of the section is located 6,500 feet north of latitude 39°45′ and 13,000 feet west of longitude 77°37′30″. The section proceeds west and slightly north remaining several hundred feet north of the road to the farm house.

The contact between the Shadygrove and Zullinger Formations occurs in a covered interval 280 feet wide. There is a small fold present on the west side of the covered interval and assuming no faulting and that the cover is all occupied by the Shadygrove Formation then its thickness is about 210 feet. All other contacts are well exposed and conformable.



Beekmantown Group
Stonehenge Formation (Not Measured)
Stoufferstown Formation (261 feet thick)

Unit		*Thickness (In feet)*
1.	Limestone, medium-dark-gray, weathers light gray; it is mechanical, laminated with many beds up to 1½ feet thick of intraformational and edgewise conglomerate; the more finely grained mechanical limestone has laminae and bands of argillaceous dolomite; at intervals of several feet, are zones up to 6 inches thick of gnarly siliceous dolomite bands which Sando (1958) refers to as siliceous seams; there are some yellow-orange flecks in some of the intraformational conglomerate beds.	58.5
2.	Limestone, dark-gray, weathers light blue gray, medium-grained mechanical in most part, but ranges to fine intraformational conglomerate in part; abundantly seamed throughout with argillaceous dolomite forming light-brown crinkly partings, in a few places it has thicker siliceous dolomitic partings.	12.0
3.	Limestone, light-blue-gray, in fine- to medium-grained mechanically laminated bands with some fine intraformational conglomerates and many subplanar bands of medium-yellow-orange argillaceous dolomite; very rare gnarly dolomite bands; in places the dolomite laminae come together to give a boudinage affect.	13.5

Unit		*Thickness (In feet)*
4.	Limestone similar to Unit 2, but with more seams of argillaceous dolomite and fewer seams of siliceous dolomite; a 2-foot oolite bed is also present; 40 percent exposure in this unit.	153.5
5.	Interbanded light-blue-gray limestone and brownish-gray argillaceous dolomite that gives a gnarly aspect to the outcrop and forms a prominent ridge; a chippy soil is formed from this limestone; the dolomite bands average ¼ to ½ inch in thickness.	4.0
Conococheague Group		
Shadygrove Formation (786 feet thick)		
6.	Limestone, medium-dark-gray, weathers light blue gray; micritic to very finely grained mechanical, with irregular ⅛- to ¼-inch bands of light muddy gray dolomite and light-brown argillaceous dolomite partings that are highly irregular to anastamosing but parallel to bedding; the light muddy bands are less irregular; 70 percent exposed.	19.0
7.	Limestone, intraformational conglomerate to coarse-grained mechanical limestone with large algal-stromatolite heads present, in places form complex of algal-stromatolite heads and channels; with flecks of yellow-orange (10YR 7/6) fossil and fragmental pieces.	2.0
8.	Limestone, similar to Unit 6.	11.0
9.	Covered interval.	17.0
10.	Finely interlaminated, blue limestone and yellow-orange dolomite; laminae are planar and parallel to bedding; all appear to be mud cracked with 3:1 elongation of the polygons parallel to the regional B axis; mud cracks penetrate in excess of 1½ feet.	5.0
11.	Limestone, dark-gray, weathers light gray; micrite in places to very finely grained mechanical with abundant irregular seams of yellow-orange argillaceous dolomite; the limestone appears crisscrossed on ¼- to ½-inch spacing by these seams.	48.7
12.	Limestone, light-medium-gray; intraformational conglomerate with clasts to 1½ inches, rounded, tabular; with medium-grained mechanical and bioclastic limestone lenses.	1.8
13.	Limestone with subordinate interlaminations of dolomite; the limestone is medium-gray and very finely grained mechanical; with abundant dolomite laminae, ranging in places to interlaminated with dolomite.	4.5
14.	Limestone, blue-gray, weathers light blue gray; this is probably algal-stromatolite limestone with a few thin argillaceous dolomitic partings; 50 percent exposure.	29.7
15.	Covered interval.	66.0
16.	Finely interlaminated limestone and dolomite, blue-gray; the laminae are planar and parallel to bedding; dolomite laminae are more yellow-orange in color.	3.6

Unit		Thickness (In feet)
17.	Banded limestone, light-blue-gray (N6.5); fine-grained mechanical, with ⅛- to ½-inch bands of yellowish-orange (10YR9/5) dolomitic limestone showing scour and fill, graded bedding, and burrowing structures; some silt and sand are present in the dolomitic limestone.	11.8
18.	Limestone, dark-gray, light-blue-gray weathering, micritic structureless, very pure; 10 percent exposed.	11.6
19.	Dolomitic limestone, laminated to banded, light-blue-gray to light-yellow-gray; some thin laminae to bands of medium-white quartz sand in the more dolomitic bands.	2.5
20.	Limestone, light-olive-gray, weathers medium blue gray, micritic to very fine-grained mechanical with abundant irregular seams of reddish-brown argillaceous dolomite.	5.5
21.	Limestone, dark-gray, weathers light blue gray, finely mechanical, shows much burrowing structure, mottlings, current structure, and algal-stromatolite growth; with seams and thin zones at 2- to 6-inch intervals of stylolites; with thin seams of quartz sand that show channeling, and one bed of intraformational limestone conglomerate. There are some large nodules up to 7 inches of light-honey-brown (10YR7/4) chert that ranges in part to light-blue in color; the chert nodules have a blocky character.	35.8
22.	Similar to Unit 21.	5.0
23.	Dolomite, shades of gray (5Y7/2), weathers medium gray (N6); massive to crudely laminated; grades into limestone; with some ½-inch thick bands of bluish dolomitic limestone.	1.0
24.	Limestone, medium-gray, weathers light gray, very finely mechanical, structureless with abundant films of argillaceous dolomite in seams that are stylolitic in part; seams are very irregular but are subparallel to bedding.	2.6
25.	Limestone, olive-gray, weathers light gray (N7), finely mechanical, laminated to structureless with some layers of dispersed fine-grained fossil fragments that occur partly as calcite crystals; with some yellow- to olive-muddy-gray (5Y7/1) dolomitic limestone laminae that are planar and parallel to bedding but discontinuous, from ⅛ inch to ¼ inch of thickness; they do not weather differentially from the adjacent limestone, this forms a distinctive and characteristic portion of this formation.	1.3
26.	Dolomitic limestone, medium-gray, with planar dolomite laminae that are in part chertified.	0.4
27.	Dolomite, yellowish-orange (5Y7/2), weathers medium light gray (N.6), massive, crudely laminated, grades into limestone.	2.0
28.	Limestone, light-medium-gray, very finely mechanical with abundant planar yellowish-gray dolomitic laminae and irregular burrowings and pods, in beds 6 inches to 1 foot thick; 50 percent exposed.	50.0
29.	Covered interval.	80.7

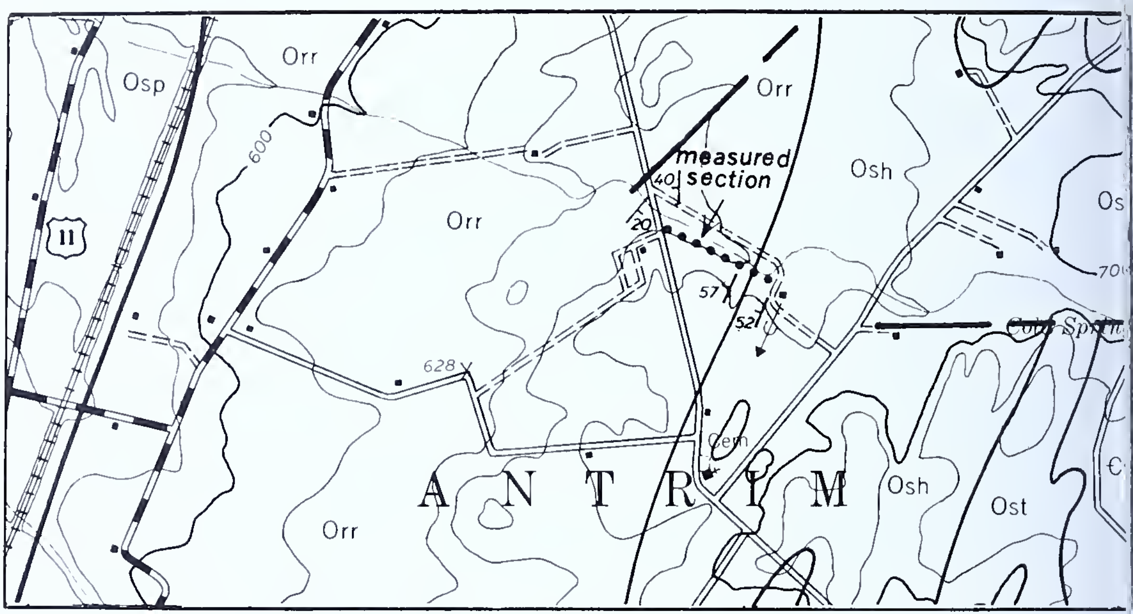
Unit		*Thickness (In feet)*
30.	Pure limestone, dark-gray to medium-gray, weathers light gray; in large part it is algal stromatolite with dolomitic laminae in the algal-stromatolite channels; some beds 6 inches to 1 foot thick are bedded mechanical to skeletal limestone with planar muddy gray dolomite laminae and interbands which do not weather in relief; there is a pinkish cast to the rock especially when wet; abundant chert float in the field with nodules to 9 inches long of honey-brown to pinkish-brown, coarse, blocky chert; also one bed with floating quartz-sand grains; this lithology is typical of this formation.	130.0
31.	Covered interval.	44.0
32.	Limestone, light-blue-gray, micrite with pinkish cast and with pink calcite veins.	3.0
33.	Covered interval. Calculated stratigraphic thickness in this interval.	210.0
Conococheague Group		
Zullinger Formation (225 feet—incomplete)		
34.	Limestone, medium-gray at base and top with a few muddy-gray dolomite bands in the middle portion; this is an algal-stromatolite limestone with the inter-stromatolite channels filled with mechanical limestone.	24.5
35.	Interbanded limestone and dolomite; limestone is dark-gray (N3) and weathers dusky yellow (5Y6/1), it is very finely mechanical, structureless to in part laminated; with some 1-inch thick lenses of skeletal material. The dolomite bands are dark-gray (N2), weathering yellowish-orange (10YR5/2); dolomite bands are very argillaceous and in part laminated; they are similar to seams in the Stoufferstown Formation; bands are subplanar to anastomosing in part and ¼ inch to ½ inch in thickness. This unit is a prominent ridge former.	56.4
36.	Limestone, light-medium-gray to medium-gray; mechanical in part with intraformational conglomerates, with abundant thin dolomitic partings and bright orange dolomite flecked fossils; all in beds 3 inches to 1 foot thick with a couple 1-foot beds of gnarly interbanded limestone and dolomite; 30 percent exposure.	38.0
37.	Covered interval.	64.3
38.	Limestone, medium-gray to dark-gray, weathers very lightly gray; micritic to very finely mechanical, internally structureless except for small ¼- to 1½-inch angular patches of bright yellow-orange dolomitized fossils. This is quite a pure limestone, in beds about 6 inches to 1 foot thick and probably algal in part; near the top some thin discontinuous muddy gray dolomitic laminae are present.	29.0
39.	Interbanded limestone and dolomite. The limestone is medium-gray and in bands 1 to 2 inches thick; micritic to very finely mechanical. Dolomite forms 40 percent of the unit and is grayish-orange in color and silty. Interbanding is wavy to boudinagelike. The unit is massive.	

Unit		*Thickness (In feet)*
40.	Algal-stromatolite limestone, medium-gray, weathers light gray; it is a micrite and structureless with thin highly irregular dolomite laminae outlining the algal-stromatolite heads; unit is massive.	11.5
41.	Intraformational limestone conglomerate, with maximum clasts 2 inches, well-rounded and tabular, with light-buff dolomitic matrix; the conglomerate is edgewise in part.	1.7
42.	Limestone, dark-gray, weathers medium gray, very finely mechanical to micritic, in bands 1 to 3 inches thick; with 20 percent bands of silty dolomite, yellow-orange in color (10YR6/4) bands are about ¼ inch thick and wavy to anastomosing.	5.3
43.	Covered interval.	4.7
44.	Limestone, medium-blue-gray, intraformational conglomerate, maximum size of clasts 2 inches; clasts are well-rounded and tabular with a light-buff dolomitic matrix, alignment of clasts is subparallel to bedding.	1.3
45.	Limestone, medium-gray, weathers medium blue gray, finely mechanical, highly fractured with abundant calcite veining. No outcrop east of this unit and a large fault is present in the covered interval.	2.3

LOCALITY 3—ANTRIM CHURCH SECTION

The section near the Antrim Church has been measured to illustrate the pure algal-stromatolite limestone and cherts that comprise the basal several hundred feet of the Rockdale Run Formation. The uppermost part of the Stonehenge Formation is also included. All contacts are conformable.

The base of the section is located 14,500 feet east of longitude 77°45′ and 21,500 feet north of 39°45′. From this point the section proceeds west-northwest on the south side of the creek that flows to the old stone farmhouse. The section terminates at the synclinal axis close to Interstate 81.



Beckmantown Group

Rockdale Run Formation (421 feet—incomplete)

Unit		*Thickness (In feet)*
1.	Algal-stromatolite limestone, L-L-H type, very pure limestone, medium-gray (N5), weathers medium gray (N6); with fine light-yellow-orange dolomite laminae that outline the algal-stromatolite form; with several small lenses of coarsely-grained mechanical limestone.	5.5
2.	Limestone similar to Unit 1, but with fine tubular network of gray, limy dolomite with a purplish cast when wet.	2.0
3.	Dolomite, medium-gray (N4), weathers medium light gray (N6.5); appears to be a local dolomite as it cannot be traced laterally for any extent.	0.5
4.	Limestone, similar to Unit 1 in lower part with very sparse muddy gray dolomitic bands, subplanar; in the upper part it has a pinkish cast when wet. Intermittent exposures in this interval.	60.5
5.	Covered interval.	45.0
6.	Limestone, similar to Unit 1.	4.0
7.	Poorly exposed; rock composed of patchy limestone and dolomite.	0.5
8.	Dolomite, medium-light-gray (N6), weathers yellow gray (5Y7/2), slightly limy, microcrystalline and faintly laminated but mostly structureless.	4.0
9.	Covered interval.	11.2
10.	Limestone, similar to Unit 1.	4.5
11.	Limestone, dark-gray (N4), weathers medium light gray (N6.5), micrite, well-bedded in 6-inch beds with some fine dolomite laminae.	14.0

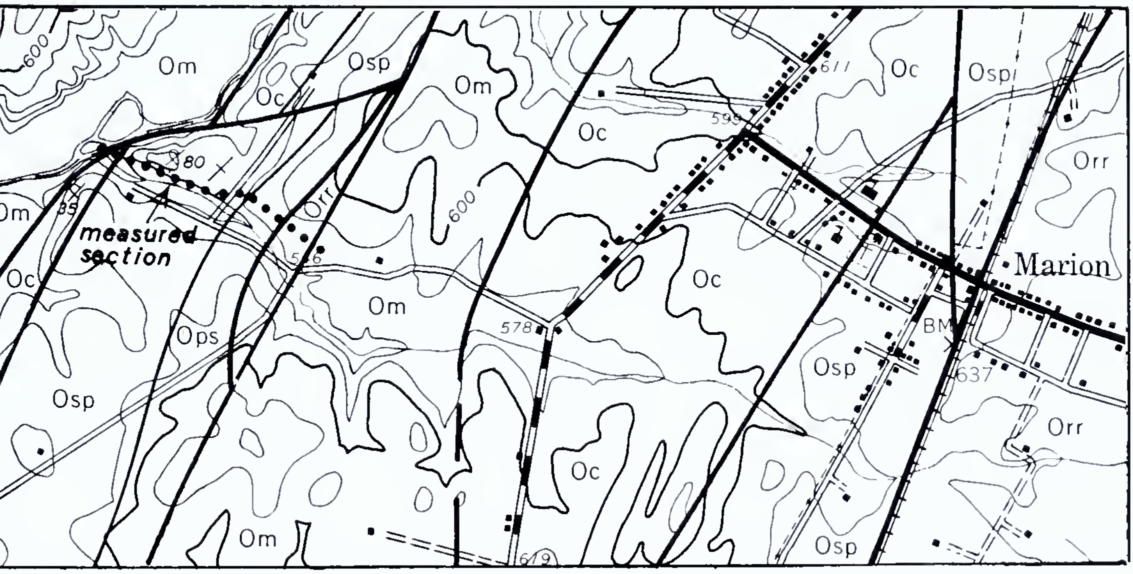
Unit		*Thickness (In feet)*
12.	Algal-stromatolite limestone, medium-olive-gray, (5Y5/1) weathers medium light gray (N6.5) very pure with a vaughanitic appearance; no laminae showing outline of form, but bedding is seen to generally pinch and swell indicating some algal-stromatolite habit; with a very few white dolomitic partings in this unit. There are several pink marbleoid horizons in this interval at 13.5, 27.0, 62.0, 85.5, 100.0, and 160.0 feet above the base of the unit; unit is about 30 percent exposed.	174.0
13.	Algal-stromatolite limestone, L-L-H type, very pure, light-olive-gray weathers light blue gray. It has a waxy appearance with several 1-foot thick pink marbleoid beds in the upper half of this unit; with an especially good development of stromatolite heads in the upper part and light-honey-brown chert nodules up to 12 inches across in the stromatolite heads; 50 percent exposure in this interval.	22.5
14.	Algal-stromatolite limestone, moderate-pink-orange (5YR7/4) with irregular paler mottlings; with a saccharoidal texture on the fresh surface and marblelike appearance on the weathered surface; with nodules up to 8 inches across of creamy chert.	
15.	Algal-stromatolite limestone, L-L-H type in beds 1 to 2 feet thick of solid algal limestone; very pure medium-gray (N5), weathers medium light gray (N6) with a few light-yellow-orange dolomitic laminae outlining the algal form; with several small lenses of coarse-grained mechanical limestone; nearer top are sparse, small, 3-inch thick lenses of creamy white chert nodules and chert replacement of the fossils. Thirty percent exposed.	32.0
16.	Limestone, medium-gray, weathers light blue gray; micrite in the lower part and a very few laminae in the upper part; with much skeletal material; few dolomitic laminae and bands in the lower part and a very few laminae in the upper part; 6 inches to 1½ feet thick.	36.0
17.	Dolomite, medium-dark-gray, (N4.5) weathers yellowish gray (5Y7/1); very finely laminated but all laminations occur in discrete patches that are cross-bedded, or that show scour-fill structures, or that show burrowing structures, or show horizontal laminations, or intraformational conglomerates; with abundant interlaminations and some ½-inch thick bands of blue-gray limestone. This is a distinctive dolomite that is unlike any dolomite above and below it.	4.0
Beekmantown Group		
Stonehenge Formation (238 feet—incomplete)		
18.	Limestone, medium-dark-gray, weathers light blue gray; all mechanical to very intraformational conglomerate with skeletal detritus throughout; abundant fine yellow-brown irregular argillaceous dolomitic laminae throughout, parallel to bedding; unit is in 3-inch to 1-foot thick beds. *Bellefontia* collected from here. Thirty percent exposures.	86.5

Unit		*Thickness (In feet)*
19.	Algal-stromatolite limestone, dark-gray weathers light blue gray; consists of vertically growing pipelike stromatolite heads with a height of 4 feet and with channels containing mechanical and dolomitic banded limestones; in places these coalesce to form a single algal-stromatolite bed. The internal form of the stromatolites are shown by medium-yellow-gray argillaceous dolomitic partings, some fossil fragments both in mechanical limestone channels and in algal-stromatolite colonies.	20.0
20.	Limestone, medium-dark-gray, weathers blue gray; medium-grained mechanical rock with abundant fossil fragments to very fine conglomerates; contains 30 percent light-yellow-orange dolomitic laminae and bands, some are subplanar and some anastomosing to give a boudinagelike effect; in beds 6 inches to 1 foot.	15.3
21.	Covered interval.	2.4
22.	Limestone, dark-gray, weathers medium blue gray; very finely conglomeratic with a couple of black siliceous limy partings (gnarly limestone).	1.0
23.	Limestone, with interbands of dolomite; the limestone is dark-gray and weathers to light gray, is very finely mechanical to in part micritic, contains 30 percent yellow-orange-brown dolomite bands that are subplanar to anastomosing.	14.9
24.	Limestone, intraformational conglomerate, in beds 2 to 6 inches thick with a few partings of argillaceous dolomite, yellow-orange fossiliferous flecks throughout.	21.5
25.	Limestone, fine intraformational conglomerate to coarse-grained mechanical limestone; in beds 2 to 6 inches thick; with a few partings near top of black siliceous dolomitic shale (gnarly).	6.0
26.	Interbanded limestone and dolomite. The limestone is dark-gray and weathers light gray; it is mechanical to microconglomeratic and in bands ½- to 3-inches thick. With 30 percent argillaceous dolomite bands that are parallel to bedding and subplanar to anastomosing in part; with several bands to 2 inches thick of siliceous dolomite shale (gnarly dolomite).	9.5
27.	Limestone, intraformational conglomerate, in lower part edgewise conglomerate with clasts to 3 inches, rounded and tabular; contains medium-grained mechanical matrix. There are flecks and spots of yellow-orange carbonate. With a single parting (⅛ inch) of black siliceous gnarly dolomitic shale.	6.5
28.	Limestone, medium-dark-gray, weathers light gray; coarse-grained mechanical with abundant fossil fragments in places; in lower part thin-bedded and fairly pure; in upper part abundant 30 percent yellow-orange anastomosing argillaceous dolomitic laminae and bands; thin-bedded; 30 percent exposure.	54.5

LOCALITY 4—ST. PAUL GROUP

This section, measured in a general way only, is intended to illustrate the lithologies of the St. Paul Group. It also illustrates lithologies of the limestone–dolomite sequence referred, by this writer, to the Pinesburg Station Formation of the Beekmantown Group.

The base of this section is 6,000 feet west and slightly north of the railroad crossing in the town of Marion. It is on the north side of the road at Kauffman's farm and corresponds to Neuman's (1951) section 31 near Marion. The section proceeds west, up section, from the faulted contact of the carbonates and Martinsburg Formation to Conococheague Creek where Chambersburg limestones are exposed. A sketch map of this traverse is included in MacLachlan and Root (1966, Figure 10).



St. Paul Group (approximately 1,000 feet thick)

New Market Formation (580 feet thick, approximately)

Unit		*Approximate Thickness (In feet)*
1.	Micritic limestone (vaughanite) interbedded with fine detrital to skeletal limestone. Above this are cobbly limestones of the Chambersburg Formation.	135
2.	Bluish-gray limestone, fine detrital to skeletal, banded in part, faulted and folded in upper part.	170
3.	Cyclical carbonates consisting of blue-gray algal limestone and buff laminated dolomite. Perhaps nine cycles are present.	125
4.	Limestone, very fine detrital, laminated, with beds and bands of skeletal limestone; abundant black chert nodules at base and some at top of unit.	150
Row Park Formation (400 feet thick approximately)		
5.	Covered interval.	54
6.	Limestone, skeletal to detrital, medium-grained, finely banded.	165
7.	Limestone, bluish-gray, skeletal, finely banded with large specimens of *Maclurites* and some *Receptaculites*.	77
8.	Limestone, pure micrite (vaughanite) with 'birdseye' structure.	106
Beekmantown Group		
Pinesburg Station Formation (possibly about 300 feet thick)		
9.	Dolomite, medium- to light-gray laminated.	1
10.	Limestone.	32
11.	Dolomite.	5
12.	Limestone.	13
13.	Dolomite.	12
14.	Limestone, blue- to blue-gray, with muddy gray laminations and bands, planar to subplanar, some dolomite interbands and laminae.	103
15.	Covered interval.	40
16.	Limestone, blue- to blue-gray, with six discrete beds 2 to 3 feet thick of light-gray laminated dolomite.	106
17.	Limestone, blue-gray, thin-bedded, crystalline, fractured in part. Possibly Rockdale Run Formation.	50
18.	Limestone, highly fractured and brecciated due to faulting.	115

Below this is about 100 feet of faulted and brecciated limestone whose stratigraphic position is uncertain.

2674

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
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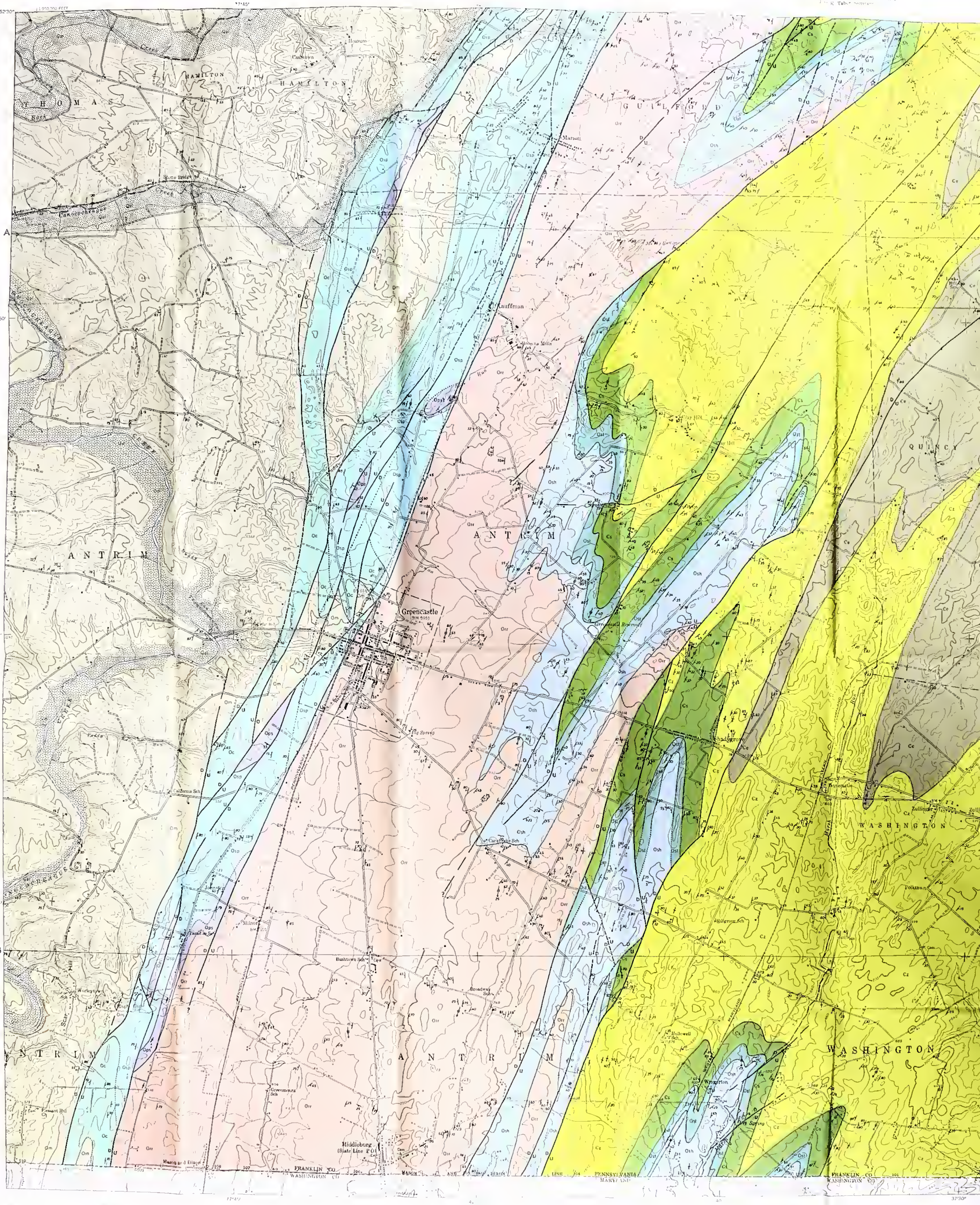


Base map compiled from U.S. Geological Survey Greencastle, Hagerstown, Mason-Dixon, Smithsburg, Waynesboro, and Williamson 7½-minute quadrangles.

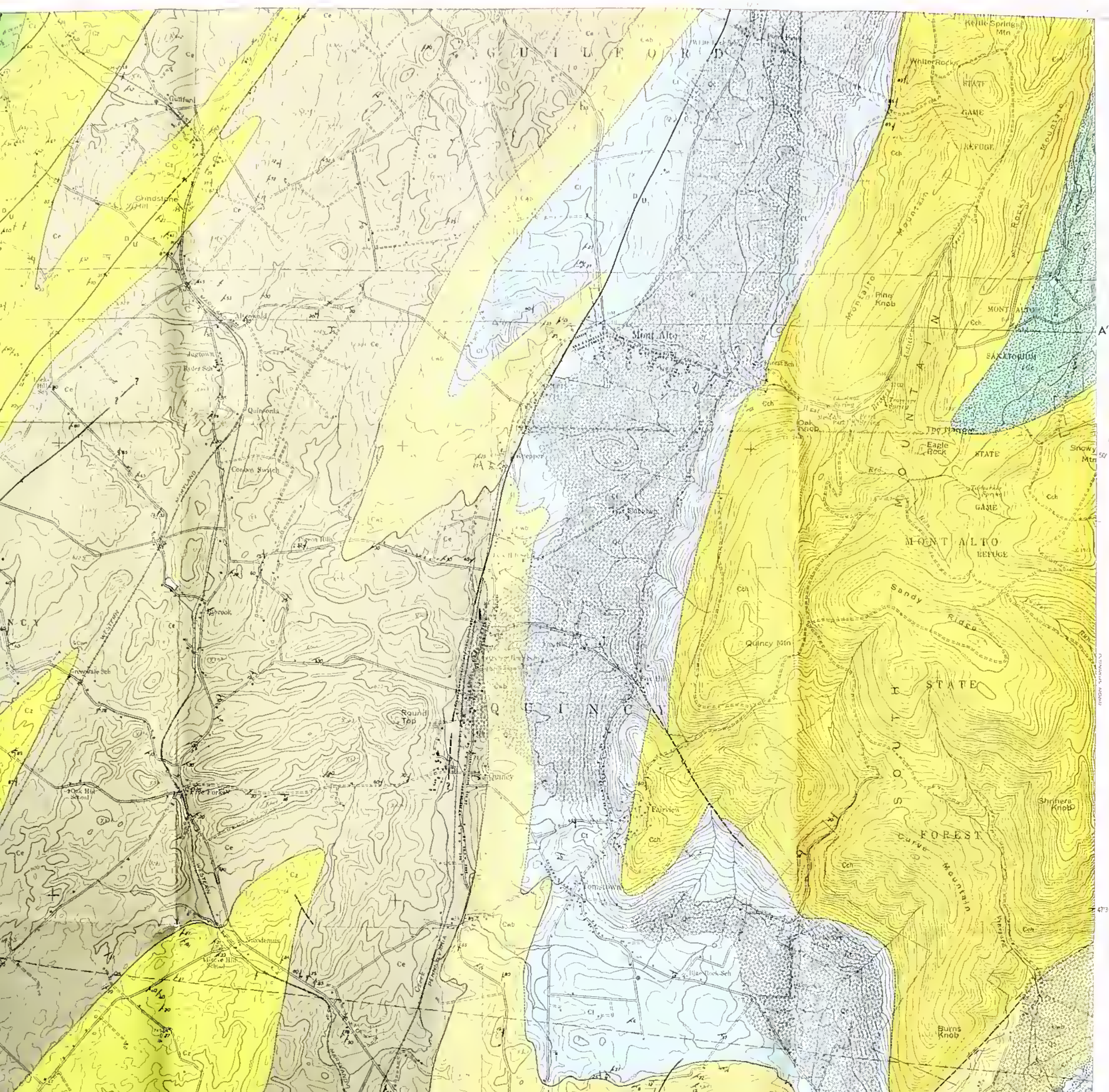
SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGIC MAP OF GREENCASTLE AND WAYNESBORO QUADRA
AND PARTS OF ADJOINING QUADRANGL

BY
SAMUEL I. ROOT
1968

Atlas A119cd, Plate 1



EXPLANATIONS

TERTIARY-QUATERNARY

Quaternary

Qal

Alluvium

Unconsolidated silt and sand sufficiently thick to conceal the bedrock

Cretaceous (?) Tertiary-Quaternary

Qt

Colluvial and terrace gravels

Colluvial material and terrace gravels undifferentiated

ORDOVICIAN

Middle and Upper Ordovician

Om

Martinsburg Formation

Black, carbonaceous and fissile shale, weathers buff with yellow-green to dark-gray, fine-grained graywacke beds.

Middle Ordovician

Oc

Chambersburg Formation

Dark-gray, cobbly limestone, argillaceous with abundant irregular shaly partings. Some metabentonite beds present.

Osp

St. Paul Group

Vaughanitic limestone at top. Granular fossiliferous limestone, black chert, and sparse dolomite. Vaughanitic limestone at base.

Lower Ordovician

Beekmantown Group

Ops

Pinesburg Station Formation

Light-colored, thick-bedded, finely-laminated dolomite. Includes some limestones in northern part of area

Orr

Rockdale Run Formation

Mostly limestone, some dolomite interbeds. Some chert near middle and top. Mechanical and stromatolitic limestones in middle part. At base 600 feet of pinkish marbleoid limestone and chert.

Osh

Stonehenge Formation

Stromatolitic and fine mechanical limestones that become predominantly mechanical toward the north

Ost

Stoufferstown Formation

Coarse mechanical limestones with dark-gray siliceous seams, prominent ridge former.

CAMBRIAN

Upper Cambrian

Conococheague Group

Cs

Shadygrove Formation

Pure light-colored limestones, stromatolitic in part. Abundant pinkish limestones and cream-colored cherts

Cz

Zullinger Formation

Cyclically-bedded, stromatolitic-mechanical limestone, interbanded limestone and dolomite, interlaminated limestone and dolomite, thin dolomite. Several thin local quartz sand beds.

Middle Cambrian

Ce

Elbrook Formation

Light-colored, calcareous shale and argillaceous limestone, blue limestone and dolomite in middle-ridge former. Pure dark limestone at base.

Lower Cambrian

Cwb

Waynesboro Formation

Thin basal and upper red ridge-forming sandy units. Middle portion is blue limestone.

Ct

Tomstown Dolomite

Dolomitic limestone to limestone in upper part. Mottled silty dolomite in middle part. No exposures at base.

Lower Cambrian and (?) Precambrian

Cch

Antietam Formation—*White quartzite with bluish-cast in places, coarse grained, pure, with many Skolithus tubes. Lowermost Cambrian fauna.*

Harpers Formation—*Dark-banded, hackly schist to slate with prominent middle member of massive hard, white quartzite that thickens to the north.*

Weverton Formation—*Gray feldspathic sandstone, coarse. Some white quartzites. Conglomerate at base*

PRECAMBRIAN

p€c

Catoctin Formation

Altered rhyolite flows, finely-laminated, red to purple color. Altered basalt with chlorite and epidote.

SYMBOLS

Definite contact

Inferred contact

Concealed contact

Strike and dip of beds

Strike and dip of beds where it is known which side is up

Horizontal beds

Strike of vertical beds

Strike and dip of overturned beds

Generalized strike and dip of crumpled, plicated, crenulated, or undulating beds

Strike and dip of foliation

High angle fault—U, up; D, down
Arrows show dip where known

Fault showing relative movement

Anticline
Syncline
Strike and plunge of minor fold showing degree of plunge

Anticline
Syncline
Strike and plunge of overturned minor fold

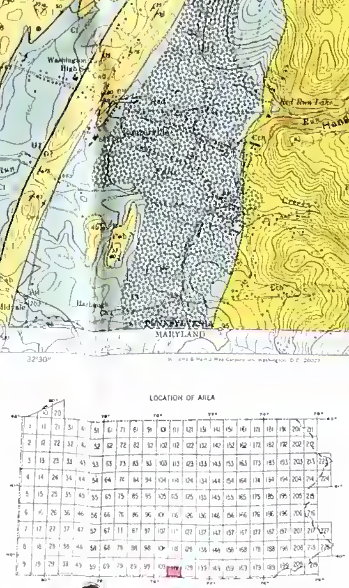
Axis of anticline

Axis of syncline

Quarry

Williams & Heintz Map Corporation, Washington, D.C. 20027

LOCATION OF AREA



D QUADRANGLES, PENNSYLVANIA
ADRANGLES

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
John K. Tabor, Secretary

GEOLOGIC CROSS SECTIONS OF THE GREENCASTLE AND WAYNESBORO

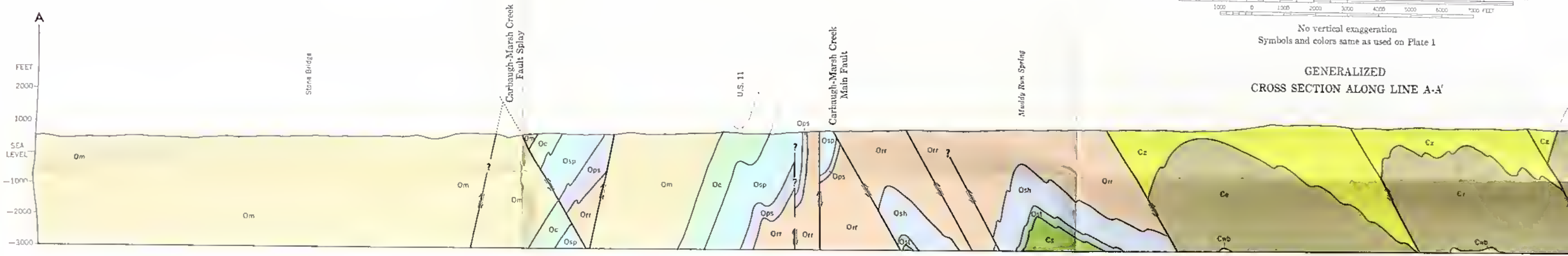
BY

SAMUEL I. ROOT

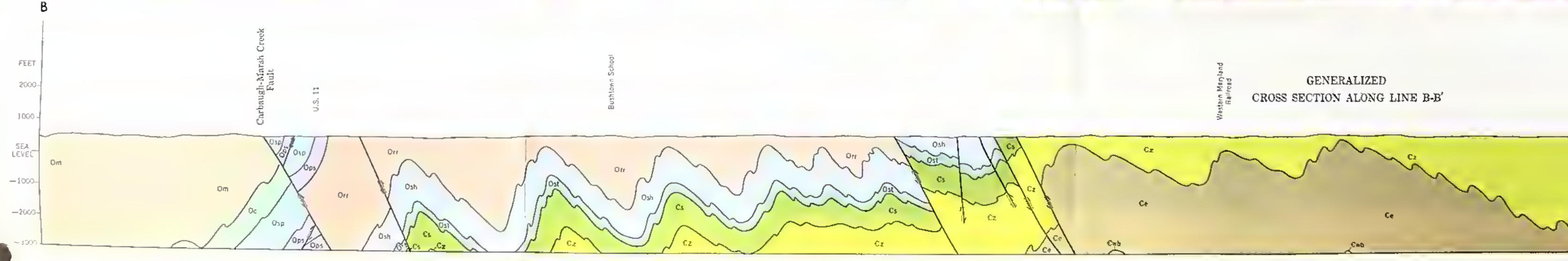
1968

SCALE 1:24000

No vertical exaggeration
Symbols and colors same as used on Plate 1



GENERALIZED
CROSS SECTION ALONG LINE A-A'



GENERALIZED
CROSS SECTION ALONG LINE B-B'

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
John K. Tabor, Secretary

GREENCASTLE AND WAYNESBORO QUADRANGLES, PENNSYLVANIA

BY
SAMUEL I. ROOT
1968

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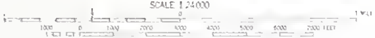

No vertical exaggeration
Symbols and colors same as used on Plate 1

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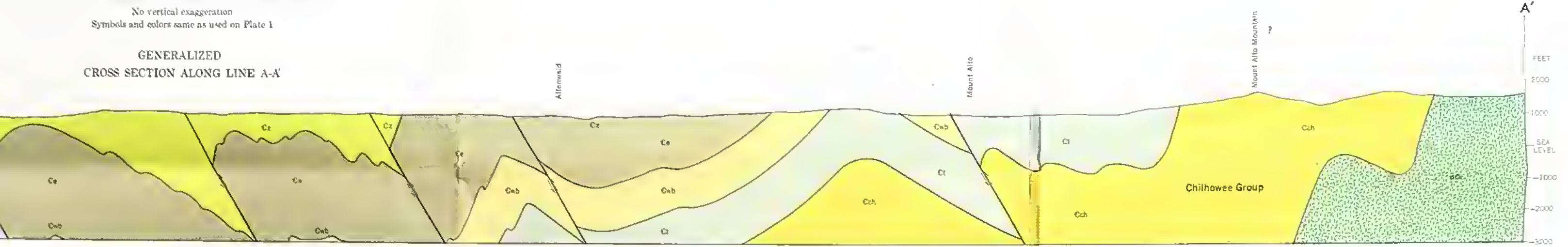
CROSS SECTION ALONG LINE A-A'



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